HENLEY'S ENCYCLOPÆDIA

OF

PRACTICAL ENGINEERING

AND ALLIED TRADES

A PRACTICAL AND INDISPENSABLE WORK OF REFERENCE
FOR THE MECHANICAL ENGINEER, DESIGNER, DRAFTSMAN,
SHOP SUPERINTENDENT, FOREMAN AND MACHINIST.

Encyclopædic in scope, thorough and practical in its treatment of technical subjects, simple and clear in its descriptive matter, and without unnecessary technicalities or formulæ. The Articles are as brief as may be and yet give a reasonably clear and explicit statement of the subject, and are written by men who have had ample practical experience in the matters of which they write.

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"TOOLS FOR MACHINISTS, AND WOODWORKERS,"
ETC., ETC.

ASSISTED BY A CORPS OF PRACTICAL MEN, EACH A SPECIALIST
IN THE SUBJECT OF WHICH HE WRITES.

PROFUSELY ILLUSTRATED.

VOL. I.

A–BOI.

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PREFACE.

THE publication of this comprehensive work, intended to cover the entire practice of civil and mechanical engineering, is justified by the present conditions of that practice. Men in the offices and shops, in active professional and commercial work, and students in the schools are all to a great extent hampered by the ever-extending character of engineers' work, and its intensified specialisation. The term "engineering" alone has now too vague a meaning to denote anything definite, without some qualifying prefix. The vast profession, or industry, or craft, is subdivided into more than a hundred well-defined and separate fields, and many of these are broken up into still more specialised departments. It is thus a fact, that competent and experienced engineers who have devoted their whole lives with absolute singleness of purpose to their chosen pursuits, cannot possibly intimately know the practice of more than a few of the related sections. Every great industry in which motors and machines are used is now catered for by manufacturers who mostly confine their business to the demands of a single industry, and in which alone their experience lies. Of all outside that, their knowledge is in a sense that of amateurs.

What is true of the individual fields of action is true also of the separate crafts which are carried on in the separate shops and sub-departments of a single big works. The divisions between these, following the passing of the old race of mill-wrights, grow sharper, more stringent, and more minute as time goes on. A workman is no longer a turner, or a machine hand, or a boilermaker, or a moulder, but he is a man doing one sub-section of work, or an attendant of one kind of machine. He is also either a mechanic, or a machine-minder. His speciality is thus as well defined as that of the group of manufactures carried on in the firm of which he forms a unit.

This intensity of specialisation produces narrow views, and narrow ideals, and tends to induce only a languid interest in the related work that lies beyond. It renders the acquisition of minute knowledge in the other fields very difficult. Especially on those of limited means do these conditions press hardly. The mass of technical literature is too great to be purchased or even assimilated, neither is it essential except to a few. The requirements of most people are met by a special knowledge in one branch, and a general acquaintance with others related thereto. Hence the popularity enjoyed by encyclopædias of a literary and scientific cast.

PREFACE.

It is believed that there is scope for such a work for the engineering and allied trades. Almost every one makes or uses machinery now, and to all such, whether employers, or workpeople, these volumes will appeal. It is hoped that nothing which is of interest to those engaged in any of the Engineering industries will be omitted from its pages. All the different subdivisions have been well considered in the selection of subject matter, and in the due balance of articles, according to their relative importance

None know better than those who are engaged in the work, how inadequate the space included within ten volumes is to deal with all that is involved in present-day engineering in its numerous branches. Brevity is necessary, yet this must not be secured at the sacrifice of comprehensiveness. A method of treatment is however adopted which will combine and balance both requirements. No articles will be very long, but there will be many separate articles on related subjects of importance. The idea is, that a reference to a tool, or machine, or process will be found under the heading that first occurs to the mind. This will be preferable to an arrangement involving long articles, in which one has to hunt through many pages for some bit of information. Cross-references will also assist in finding any article wanted.

A special feature of this work is its "shoppy" character. It is written for the men in the shops more than for any other class. For this reason too it is of especial value to students, who, whatever they may learn of theory in technical schools, certainly do not learn shop work as it is performed under factory conditions.

The contributors are mostly men whose names are well known as reliable writers on technical matters, and who either have been, or are engaged in active engineering pursuits.

A feature of these volumes is that all the blocks have been made specially for the work from drawings prepared uniformly under the Editor's supervision, or from photographs. It would have been easy to fill the work with borrowed catalogue blocks at a considerable saving of expense, but the publishers have wisely decided to give subscribers original drawings instead—a more satisfactory course. The illustrations of machines, &c., have been prepared from originals supplied by representative firms. In all cases they are to exact scale, being reduced proportionately, and they are therefore of as much utility as though dimensioned up. Representing as they do therefore actual practice in manufacture, their superiority over bald diagrams, or patent specification drawings, is evident. These, though used freely in many books, too often convey but a poor and incorrect idea of a mechanism as it is commercially made—scale and proportions of parts especially being bad.

It is with great pleasure that the Editor records his sense of the courtesy with which so many firms have freely placed working drawings at his disposal for this work.

THE EDITOR.

The Encyclopædia

OF

Practical Engineering and Allied Trades.

A1.—The highest classification of vessels in Lloyd's Register of British and Foreign Shipping. The letter A has reference to the hull, the figure 1 to the equipment of a vessel.

The classification of vessels is sanctioned by the Committee of "Lloyd's Register" on the basis of Reports sent in by their Surveyors, who are located at all the principal ports of the world. Surveys may take place during or subsequent to the construction of the vessels, full particulars for the carrying out of which are given in the "Rules and Regulations" issued by the Society. These surveys are strict, without being of a hard-and-fast character. That is, though the officers of the Society have no power to sanction deviations from their printed conditions and the Rules laid down for their guidance, deviations from the Rules are often sanctioned by the Committee, provided these are equivalent to the requirements of the Rules. In any case, drawings have to be supplied, giving particulars of the scantlings of the vessel, the tests of steel used (in the case of steel vessels); coal bunkers have to be cleared; all the vital portions, as frames, stringers, floor plates, keelsons, engine and boiler bearers, ends of beams, water-tight bulkheads, rivets, and inner surfaces of the plating, all exposed to view; with other provisions made in order to facilitate inspection. The Committee then, from the data furnished to them, assign the vessel to her class.

The retention of a vessel in a certain class depends on periodical surveys, which are compulsory.

The letter A, relating to the hulls of steel vessels, is prefixed by the numbers 100, or 90, thus:—100A or 90A:—and the classification is retained "so long as they are found upon careful annual and periodical survey to be in a fit and efficient condition for the safe conveyance of dry and perishable cargoes." But vessels that do not come up to the requirements of the first-named, but which exceed those of the second, may be classed as 95A at the discretion of the Committee.

The letter A occurs in several different classes, as A for river purposes only, A for channel purposes, &c. &c., to which the name of the channel must be added, as English Channel, Bristol Channel, &c.

The figure 1 placed after the A, as 100A1, denotes that the equipment is of the highest class. If this is not found to be the case, though the hull is of the best, a dash takes the place of the figure, thus 100A—.

The "good order of the equipment" includes the proper maintenance of the masts, spars, rigging, sails, and a sufficiency of anchors and cables, the number of which increases with deck erections. Certificates of tests of anchors and cables must be produced. Anchor cranes and boats' davits are included. The survey of engines and boilers is the subject of another certificate, namely, (L.M.C.) Lloyd's Machinery Certificate, with a mark in the form of a cross prefixed.

Periodical special surveys take place in vessels classed from 100A to 90A inclusive, at periods of four, eight, and twelve years respectively from the date of building, and subsequently at the expiration of like periods from the date recorded in the Register Book of the previous special survey No. 3. But if a vessel is submitted to special survey No. 3 before being

twelve years old, the special surveys subsequently required will be Nos. 1, 2, and 3, at four, eight, and twelve years respectively from the date recorded in the Register Book of the previous special survey No. 3. In vessels classed "A" for special purposes, the above surveys must take place at three, six, and nine years respectively. If more convenient to owners, surveys are made in anticipation within twelve months of the dates at which they become due.

All repairs have to be inspected at the time when they are being carried out. Appeals from the surveyor's recommendations as to repairs can be made to the Committee. Provisional certificates are given in certain cases. Classes are liable to be reconsidered on surveys, and non-compliance with Rules involves the withdrawal of the class from a vessel.

The A classification dates from the first Register Book of Lloyd's (1764). At that time the classification of hulls was denoted by the vowels A, E, I, O, and U, while letters G, M, and B referred to equipment. Thus AG denoted a first-class ship with a good equipment, while UB meant a poor ship with a bad outfit. In the next Register (1768) the numerals 1, 2, 3, 4 first appear, but the letters were small, *a*1, *b*2, &c. The earliest Register in which A1 appeared was that of 1775-76. At the date of writing, January 1905, the latest available returns gave the numbers of vessels classed thus:—

At the close of the year ended 30th June 1904, 9,672 merchant vessels, registering nearly 17¾ million tons gross, held classes assigned by the Committee of Lloyd's Register. Further details are given in the table:—

Abacus.—*See* **Calculating Machines.**

Abattoir.—A modern abattoir in the large cities is of less importance as a place for the slaughter of animals than for cold storage. It includes refrigerating machinery, steam engines and boilers, and electric machinery, as well as workshops for the repairs and renewals that are always going on. The machinery of the actual slaughtering sheds consists chiefly of conveying tackle of the overhead type, travelling on joists or "runways," secured to hangers and to the walls, and of hoisting tackle worked from the walls.

The city of Berlin has an immense municipal abattoir, in which, though the slaughtering is only done on one or two days in the week, the numbers killed include from 6,000 to 7,000 head of cattle, and from 20,000 to 25,000 pigs. In a building adjacent the engineering plant and storage chambers are contained. Here there are ten Lancashire boilers which supply steam to the engines and slaughter-houses. There are two compound tandem engines, each indicating 200 HP. and each driving two sulphurous acid compressors—that being the medium employed for refrigeration. The four compressors are able to produce from 180 to 200 tons of refrigeration per day. From these the sulphurous acid passes to three condensers containing copper coils, around which cold water is circulated by a pump, and agitated also by long blades on a vertical shaft. Thence the sulphurous acid passes to a refrigerator built of iron plates, and containing coils of copper pipes. The greater portion of this is for air cooling, but a small section is used for brine for pickling. The air supply is further cooled by passing it over trays by means of a fan running at 300 re-

Material of Construction.	Description.	British.		Foreign.		Total.	
		No.	Tonnage.	No.	Tonnage.	No.	Tonnage.
Iron and Steel -	Steam	5,543	10,437,878	2,303	4,969,146	7,846	15,407,024
	Sail	828	1,308,999	692	944,214	1,520	2,253,213
Wood and Composite	...	281	42,994	25	13,768	306	56,762
Total -	...	6,652	11,789,871	3,020	5,927,128	9,672	17,716,999

volutions per minute. The brine falls in cascades through holes in the trays. The cooled air is then carried up shafts to the chill rooms above, which are served with overhead tracks for the handling of the meat. The doors are heat insulated with double thicknesses of wood, having sawdust between them. A separate system of air coolers supplies pickling cellars. The meat is not frozen, but kept just above freezing point. But a supply of ice is made for curing. An electric generating plant supplies light to the rooms, and power to the numerous hoists connecting the floors. The engines for this plant are of 100 HP. and of condensing type, and there are two dynamos. The main building, exclusive of the slaughter-houses, is 500 feet long by 80 feet wide, and is four stories high.

Abbreviations.—The practice of substituting short signs for full terms is one which is adopted in nearly all departments of engineers' work. Many of these are of merely local and limited significance, being applicable only to a firm's own practice, but large numbers are of general utility. Selections from these are given below.

Abbreviations used on Drawings, including the Drawing Registers.—Dr. = Drawing; Tr. = Tracing; H. Sk. or Hd. Sk. = Hand Sketch; Sk. = Sketch; Bl. P. or B.P. = Blue Print; Br. P. = Brown Print; W.P. or Wt. P. = White Print.

Revs. per Min. or Revs. per ′ or R.P.M. = Revolutions per Minute; H.P. or H. Press. = High Pressure; L.P. or L. Press. = Low Pressure; Int. = Intermediate; R.H. = Right Hand; L.H. = Left Hand.

Metals and Alloys, Sections, &c.—C.I. = Cast Iron; W.I. or Wrot. I. or Wt. I. = Wrought or Malleable Iron; M. or M.C.I. = Malleable Cast Iron; C.S. = Cast Steel; M.S. = Mild Steel; G.M. = Gunmetal; C. = Copper; B. = Brass; Y.M. = Yellow Metal; P.B. = Phosphor Bronze; D.M. = Delta Metal; Al. = Aluminium; W.M. = White Metal; R.H. = Raw Hide; B.M. = Babbitt Metal; L Iron = Angle Iron; Steel L = Steel Angle; [= Channel Section; T = Tee Section; I = Joist Section; Sk. Pl. = Sketch Plate.

The sign = is used in successive positions on a drawing between dimension lines indicated by crows-feet, to denote that all the successive dimensions are alike. By this the repetition of the same dimensions is avoided. Cts. denotes Countersink, applied to the heads of rivets, screws, and bolts; Rt. = Rivet; St. = Stud; Bt. Bolt; Bl. Bt. = Black Bolt (*i.e.*, not turned); Br. Bt. = Bright or Turned Bolt; Wt. Thr. = Whitworth Thread; Sq. Thr. = Square Thread; Dl. = Drill; Bd. = Bored; Cd. = Cored; Ream. = Reamered.

Power, Temperature, Measurements, &c.—HP. = Horse Power; NHP. = Nominal Horse Power; IHP. = Indicated Horse Power; BHP. = Brake Horse Power; EHP. = Electrical Horse Power; Cent. or C. = Centigrade; Fah. or F. = Fahrenheit; R. or Rea. or Reaum. = Reaumur; B.Th.U. = British Thermal Unit; G. Cal. = Gramme Calories; Kg. Cal. = Kilogramme Calories.

In. or ″ = Inches; Ft. or ′ = Feet; Yd. = Yards; lb. = Pounds; G. or g. = Gravity; G. or Gr. = Gramme; Gal. = Gallon; M. = Metres; mm. = Millimetres; Cent. = Centimetres; KM. = Kilometres; KG. = Kilogrammes; MG. = Milligrammes; Dia. or Diam. = Diameter; Rad. = Radius; Cir. or Circ. = Circumference; Lin. = Linear; Deg. or ° = Degrees; π = Relation of Circumference to Diameter, 3·14159; μ = Coefficient of Friction; ω = Angular Velocity; E = Modulus of Elasticity; I = Moment of Inertia; Z = Modulus of Section.

Sec. or ″ = Seconds; Min. or ′ = Minutes; Hr. = Hours; Sq. = Square; Cub. = Cubic; □ in. or □″ = Square Inch; ○ in. or ○″ = Circular Inch; ∠ = Angle of; = Equal to; Sp. Gr. or S.G. = Specific Gravity; B. Pt. = Boiling Point; Fr. Pt. = Freezing Point; M. Pt. = Melting Point; °/ₒ = Per Cent.; °/ₒₒ = Per Mille.

Gearing.—P. = Pitch; P.D. = Pitch Diameter; P.L. = Pitch Line; C.P. = Circular Pitch; D.P. = Diametral Pitch; N.P. = Normal Pitch; M. or Mod. = Module = $\left(\frac{\text{circular pitch}}{3\cdot14159}\right)$.

Electrical.—E.M.F. = Electro-Motive Force; M.M.F. = Magneto-Motive Force; Kw. = Kilowatts; Kw. Hr. = Kilowatt Hour; Watt Hr. = Watt Hour; C.P. = Candle Power; C.G.S. = Centimetre-Gramme-Second System; F.P.S. = Foot-Pound-Second System; L. = Unit of Length or Centimetre; M. = Unit of Mass or Gramme; T. = Unit of Time or Second; Mega. or

Meg. = 1,000,000 Units; Myria = 10,000 Units; Kilo. = 1,000 Units; Hecto. = 100 Units; Deca. = 10 Units; Micro. or Micr. = $\frac{1}{1000000}$ of a Unit; Milli. = $\frac{1}{1000}$ of a Unit; Centi. = $\frac{1}{100}$ of a Unit; Deci. = $\frac{1}{10}$ of a Unit; Dyne = Unit of Force; Erg = Unit of Work or Energy; B.T.U. = Board of Trade Unit; E. = Volt or Electro-Motive Force; C. = Ampère or Current; Q. = Coulomb or Quantity; R. = Ohm or Resistance; J. or W. = Joule or Work; P. = Watt or Power; $\backsim$ = Frequency; $\approx$ = Alternating Current; — = Continuous Current.

See also **Algebraical Signs, Arithmetical Signs.**

Abele.—*See* **Poplar.**

Abrasion.—Abrasion, or the wear of machinery parts, due to their rubbing together, has to be taken into account by engineers in many and various ways. (This is a distinct thing from **Abrasive Processes.**) The principal factor to be considered is how to counteract the effects of abrasion, or to delay its occurrence as much as possible. The natural effect of excessive abrasion is rapid working loose of parts, and this is an evil which cannot be tolerated in the majority of machinery. The better the class of mechanism, the more perfect will be the arrangements introduced for dealing with it. Two methods are—providing hard qualities of metal, so that the effects of friction are more slowly felt; and having means for taking up wear, or effecting renewals of vital parts as they become reduced or spoilt by abrasion. The first-named precaution is a most obvious one. It comprises the use of hard cast iron, the substitution of cast steel for iron, the hardening of the portions which are most liable to be abraded, and the employment of separate pieces of harder metal, such as tips or shoes of cast steel, attached to the softer portions of mechanism not subject to friction. At the same time it must be noted that two hard substances will not run well together, so that abrasion may be actually induced if, for instance, a steel shaft is run in a steel bearing. The result is (unless very excellent surfaces are made, and abundant lubrication provided) that one face abrades and tears up the other, causing what is called **Seizing.** This is obviated by the employment of a softer metal for the bearing, as cast iron, or any of the brasses and their alloys, or white metals, and a sweet action is thus ensured. For portions, however, which only move or slide over each other slowly, two steel faces may be employed without trouble. In this class of fitting, hardening or case-hardening has very extensive use; surfaces would be rubbed away much too rapidly if it were not done, and would need frequent adjustment or renewal to keep the working parts up to action. This is especially the case with the smaller portions of mechanism, notably on machine tools, which have to endure very hard service—dogs and catches for example. Increase of area of wearing surfaces is also a method of delaying the effects of abrasion, by spreading its action over a larger amount of metal.

In the majority of cases where the presence of slackness cannot be permitted, the device of fitting adjustable parts is followed in addition to the provision just noted for delaying wear. This is done in practically all machinery, but is specially important on engines, and on machine tools of all kinds. In the first example, slackness produces knocking, with its evils; and in the second, accurate work cannot be done on a machine which lacks true guidance in its parts. By the employment of loose or adjustable pieces, close contact may be maintained between surfaces constantly. This aspect of the question will be found treated under **Adjustments, Adjusting Screws, Adjusting Strips.**

Lubrication is a means of minimising the effects of abrasion, not only to prevent or hinder wear, but also to enable easy running to be secured. Without lubrication, it is impossible to revolve shafts, and move sliding surfaces under heavy service, or at high speeds. But with a suitable oiling or greasing medium successful running is attained, the lubricant forming an interposing film between the surfaces which work together, and so lessening or preventing their abrasive action upon each other. *See* **Bearing Area, Lubrication,** &c.

Abrasive Materials.—The materials employed for abrasive processes are many, and varied in composition and quality, ranging from common sand to diamond dust. They comprise sand, grindstones, emery, corundum, carbo-

rundum, rouge, crocus, tripoli, putty powder, crushed steel, diamond dust or bort, oilstone. The great variations in the hardness and degree of finish necessary in work are sufficient to account for so many different kinds of substances being in use. Although several sorts of abrasives may be employed indifferently for certain work, there are instances where but one composition is adapted to a particular operation. Varying grades of the same material are also essential for different purposes, or for roughing and finishing processes, this being a question of coarseness or fineness of the abrading agent. The great demand for abrasives has resulted in increased supplies, and in the development and production of new materials, as well as in improvements in the applications of the existing varieties. Machinery for their employment has also been immensely developed, and the forms in which abrasives are shaped specially for use in these machines are innumerable.

Abrasives take either what we may term natural forms, *i.e.*, powders, or blocks, or they are made up into artificial shapes, to suit the purpose of their application to the work. In the former case, of which sand and natural grindstones are typical examples, the powder is used in either its loose dry state, or in a paste with liquids, and the solid stone is used in the form of blocks, or it is shaped into discs and rotated on an axle. These two instances were the first ones of the application of abrasives, but they have since been considerably affected, and in some cases ousted by other materials formed into special shapes for particular work, of which emery is the principal example.

The primitive method of abrading—using a loose powder—is practised to a large extent, and all abrasives are brought into use by this mode of working. The substances depend for their successful action upon the constant changing of position which they undergo, being rolled or rubbed about incessantly, so that fresh abrading points are exposed. There is a limit to the abrading capacity, however, of the materials, so that after a certain amount of work has been done, they begin to lose their efficiency and get dull. This is noticed in such operations as glass grinding, where sand is employed between the glass and a rubber or disc of iron; the sand has to be constantly replenished, as the used grains begin to dull and cease effective action. In this particular respect abrasives vary widely, since some kinds will do much more work than others; emery, corundum, and carborundum, for instance, are superior to sand in their endurance.

The grading of the powders for this form of abrasion produces a wide range of coarse and fine qualities suited to all classes of work. The varying grades of emery are an example of this, ranging from "corn" to "flour" sizes. For those finishes which the finest flour emery is not delicate enough to produce, other materials are employed—rouge, crocus, &c.; though these are not of so much value in engineers' work as in that of gold and silver-smiths, and various fine metal trades. The choice of an abrasive material cannot always depend upon its rapid action, since a very free and fast working material may produce too much scratching to be desirable, and therefore a more slowly operating substance must be chosen, even at the expense of time. Here, however, the value of grading comes in, since a surface can be roughed down with a rapidly working abrasive, and then finished with a smoother quality of the same or of another material. The hardness or softness also of an abrasive have much to do with the surface produced, apart from the fineness of grain. A very hard material may produce scratches, though it is finely divided, while a coarser grade of another substance may work satisfactorily.

The advent of the practice of forming abrasives into solid shapes or attaching them to the surfaces of moving bodies has resulted in a considerable extension of the use of abrasive materials. In the form of wheels, of which emery discs, and cylinders are typical, they perform all kinds of intricate operations, and other plainer ones with rapidity and accuracy. This is due directly to the device of artificially shaping the wheels into forms suitable for the application of the abrasive to the work, frequently to enable processes to be performed which could not be done at all with loose powders or pastes. The production of an efficient bond or cementing material has enabled manufacturers to mould emery and other substances into in-

numerable shapes, some of them of delicate outlines, in which a natural grindstone would be too fragile. It is also possible to make wheels in numerous grades suited to the particular requirements of various metals and finishes necessary. *See* **Grinding Wheels.**

The action of an artificial wheel while at work bears similarities to that of a powder in motion between surfaces—the particles of emery abrading the work being loosened and detached, so exposing fresh grains to operate. In the case of a revolving wheel these particles become scattered, instead of remaining between the wheel and work, so that a really more efficient and cleaner cut is attained. The loss of grains must not, however, be rapid, or the wheel will become worn away too quickly. On the other hand, retention of the particles for too long a period results in non-efficiency, because the front surface becoming dulled, ceases to operate, and the fresh grains below not being exposed, are able to do nothing. The happy mean in abrasion must therefore be struck to get the best results out of wheels, and special grades used for special work, and for different metals, hard, and soft. "Glazing," which occurs when a wheel is run too slowly, means the filling up of the pores of the wheel with the metal being ground, choking the action and stopping further abrasion from taking place.

Many of the finer grades of abrasives, chiefly for polishing, are employed when spread over revolving bobs or wheels of wood, covered with leather, &c., and on travelling belts, by which awkward shapes are tackled. All these various aspects of abrasive materials will be fully discussed under the respective headings of the substances; and their composition, manufacture, and specific uses will be described together with the machines in which they are employed. Reference may also be made to the general remarks on **Abrasive Processes.**

Abrasive Processes.—The property which certain substances possess of abrading or rubbing away softer materials is turned to valuable account in engineering, and other trades. Both the very roughest and the very finest classes of mechanical operations are alike effected by abrasion, from the fettling of castings to the finishing of high-class gauges, and lens-grinding, and polishing, work done to extremely minute fractions of the inch. The process of abrasion has peculiarities which are not possessed by true cutting tools. The extreme hardness of the abrading agent is the principal factor which enables many abrading operations to be performed, work which could not be done at all in some instances with steel cutting tools. This applies to all hardened steel pieces, and to tempered tools which can only be reduced or sharpened by abrasion. Their degree of hardness is of little account, since there is no hardened steel which cannot be easily attacked by the various abrading materials in use.

The sharpening of cutting tools was obviously one of the first human applications of abrasion, and it still constitutes the most important operation. But another function which has immensely grown during recent years is the practice of finishing pieces of work either roughly or to the most precise dimensions at present attainable. The development of this class of abrasion or grinding has opened up a new field in mechanical operations, especially in connection with hardened pieces. The advantages of hardening wearing parts have always been apparent, but the distortion which follows the hardening process imposes limits to the extent of the operation, unless some means of rectifying the effects of such distortion is available. With the advent of emery and other wheels, the truing up of hardened pieces has become a comparatively simple job, and the effect upon engineers' and other work has been far reaching.

But the most remarkable feature of the process of abrasion lies in the minute amounts of material which can be removed at a time. The case differs essentially from that of cutting tools. These must penetrate a surface to an appreciable extent before they will cut, so that very fine amounts of material cannot be taken off (except by a scraping action, which is another thing). The very finest results in finishing are therefore found to be effected by abrasion. The faintest contact, with friction of the abrading agent and the work, suffices to produce some amount of reduction, however small. What this means is that any number of separate rubbings or grindings can be made

in succession until the work has been brought to its desired state. The degree of pressure exercised during contact has a considerable effect upon the quantity of material removed, and this is a matter of sensitiveness that depends on the skill of the operator in the higher classes of abrasion. In some of this fine reduction and polishing, no machinery has yet taken the place of the human hand as a controlling agent, lens-grinding for instance, although the comparatively rough preparatory processes may be done by machine. The highly finished surfaces necessary in certain classes of work are only possible by the use of an abrasive which combines innumerable grains constantly on the move, so that no one particle can make any decided effect, or in other words, produce scratching.

Although the sharpening of tools, as previously remarked, has long been performed by abrasion, the introduction of emery and other wheels has induced a great change in the methods of dealing with certain classes of cutting tools. Those of circular shape, as reamers, boring tools, and milling cutters, were formerly softened each time it was necessary to sharpen them, and the teeth then filed, after which re-hardening and tempering was done. The many disadvantages and the waste of time involved in this method are obviated now that emery wheels can be applied to the grinding of the cutting teeth, using a special form of machine for controlling the operation. Great accuracy can be attained thus, with consequently increased economy of production. Flat-edged tools are also ground truly and economically by machine.

Although abrasion by the help of machinery has taken such an important place in workshop practice, there is nevertheless a considerable amount of work which is done by hand methods, quite apart from the precision finishing just now mentioned. The most elementary form of abrasion, that of rubbing two faces together with an abrading material between them, in the form of a powder or paste, is followed extensively. This method is employed largely for grinding in valves of various kinds, which must make a steam, or air, or gas-tight fit. A fine quality of material, emery or other kind, must be used in order to get smooth surfaces. The valves are rubbed or rotated, applying the abrading agent at intervals until perfect contact is obtained, usually over narrow surfaces. This mode of procedure, though seemingly rather crude, is the best method of giving the final fit to certain kinds of valves, especially those for gas and petrol engines, and as they wear, or become pitted during service, truing up is done on them in the same manner.

Other kinds of work are also fitted mutually by abrasion, but the method is limited to small areas, because of the inaccuracies which are likely to result if large surfaces are worked in this way. An objection to the process is that the particles of abrasive material tend to bury themselves in the work, and in soft metals that does occur. It is therefore not desirable to grind revolving shafts into soft metal bearings, because the latter retain some of the emery, &c., and continue to abrade while in service. But hard steel spindles can be ground into hard steel bearings or bushes (as in the case of lathe mandrels), and satisfactory results produced. The same applies to pins and pivots in joints of all kinds, notably those of link motions and other engine parts. Here, however, abrasion in another form is rendering mutual grinding together of less use than formerly. The circular spindles are ground instead, separately on special machines with wheels, and the holes are lapped or ground out independently to suit. An equally good fit is obtained, with more economy of time, and less trouble than by mutual abrasion with a loosely applied material.

This aspect of abrasion is one of the most striking features of the newer practice as contrasted with the older. Numerous types of machines have been, and are constantly being devised to employ abrading agents for various services, and while many machines are only for rough work, there are some which perform very precise operations. Grinding within $\frac{1}{1000}$ part of an inch can be done on the best machines, employing the means of setting provided, and finer limits can be worked to as a matter of skill on the workman's part. An interesting point about this is that the sparks arising from the contact of wheel and work while revolving are a surer guide to the fact that abrasion is

occurring than measurement is, since a faint contact and consequently abrasion may occur, the result of which cannot be measured sensibly, although the workman may be sure that reduction, however minute, is going on.

This process, therefore, once spoken of with some little contempt, as being a rather clumsy and rough operation, now takes front rank in machine shop work from the point of view of accuracy, and the precision machines which it has developed excel in fine construction those used for other work, as turning, planing, &c. Further reference will be found to these machines under their headings, in connection with the various kinds of grinding.

Previous to the introduction of such precision machines, circular work was done by the use of laps of lead, charged with abrading material, as an alternative to mutual grinding together. Accurate guidance of these, in the sense of machine work, is not possible, but good results can nevertheless be secured, and the method is employed considerably. But, like the mutual grinding, it has been greatly affected by the more economical and certain methods of the precision machines, using wheels.

Leaving this aspect of the question, we may note the extensive use of abrasives for the rougher classes of operations. There are many kinds of jobs for which cutting tools cannot be successfully employed in the reduction of the surfaces. Chilled rolls, chilled wheels, and other pieces are cases in point, but more especially we may mention that large variety of work on which only a small amount of material has to be removed, often chiefly for good appearance. A steel tool is not well adapted to taking off a thin cut from the skin of a casting or forging, the hard scale of which quickly ruins the cutting edge. Here the abrasive wheel comes in, for it is admirably suited for the dressing-off of scale, mixed with sand, and is little affected by either. For trimming and polishing all kinds of pieces, therefore, the process of abrasion is followed extensively. Stove parts are typical examples of the use of grinding wheels, sometimes no cutting tools whatever being used on them, drills excepted. The cast iron used in stove-founding is frequently of a hard nature, which cannot be successfully and rapidly attacked by steel tools, especially on shallow surface cuts, but abrasion solves the difficulty, and either plane joints may be trued up, or edges and faces trimmed and polished for good appearance. The edges of armour plates are corrected by grinding, after hardening of the faces has been done. These remarks apply also to large quantities of other metal work, where either hardness interferes with tooling, or cheapness and rapidity of trimming is essential. The rapidity of action of a grinding wheel suitable for the work is very great, quicker in many instances than a steel tool could cut off shavings. Much of the work that was once left black is now finished neatly and cheaply by grinding, and of course new classes of machinery are always being introduced, giving impetus to the practice of abrasion. A considerable amount of hand filing has been dispensed with, in favour of the more rapid grinding, especially in the rougher classes of work, from the fettling of castings to the jointing of edges and parts for agricultural machinery, steel work, wagon work, hardware, &c.

Another immense field which abrasives have all to themselves is that of polishing. The finer grades of emery, corundum, and the crocus, and allied substances, are used on buffs, mops, and on belts, and all kinds of articles are finished rapidly, with any degree of polish desired. Much of this work has been done in the past more laboriously with emery cloth manipulated by the hands. Practically any work which can be performed by hand is also capable of execution by machine. For the more awkward jobs, the travelling belts, charged with abrasive material, allow of the most awkward outlines and corners being got at.

Abrasive agents are formed into many special shapes, besides wheels, for the purpose of application, from the common emery cloth to the emery files and rubs, used in the hand. Not only is metal work abraded, but wood, granite, marble, glass, pottery, pearl, horn, leather, indiarubber, &c., are operated on by suitable materials.

The operation of abrasion involves the use of liquids in certain cases. Two purposes are served, either that of cooling, or of enabling the materials to work smoothly. Abrasion produces heat much more quickly than pure cutting

with steel tools, and the temperature of the abrasive and work rises rapidly. This is objectionable for two reasons. One is that excessive heating of the pieces will result in distortion, a thing that would ruin the majority of machine pieces; the other is that tempered tools would be softened by the heating due to the friction of abrasion. Cold water is therefore flooded over work, and the abrasive agent in cases where it is necessary, and the heat is thus kept down. Moreover, where a fine finish is required, dry abrasion is often unsuitable, so a paste is prepared, using water or oil, the latter especially, with the result that the action of the abrading material is facilitated, and yet softened and toned down, so that a fine smooth finish is imparted, free from the scratches which would be produced by dry particles rubbing on the work. Oilstones are perhaps the most familiar examples of the employment of oil. These cannot be worked dry, or abrasion will not take place to any extent, neither will the surface produced be good. But directly oil is applied, the tool being treated commences to "cling" to the stone, and a sensible amount of steel is rubbed off, constituting the sharpening.

A peculiar and modern mode of application of abrasives is that of **Sand-blasting**. Here the material is blown in a spray very forcibly on to the work, every portion being exposed to the action of the blast, which is naturally of a penetrating character. Many operations are now done in this manner which were once impossible, such as file sharpening, and other processes are done with greater facility, cleaning of metal work being one of the principal.

Detailed descriptions of the various abrasive processes will be found under their proper headings in this work. A few general remarks on the materials used are placed under **Abrasive Materials.**

Absolute Accuracy.—This term, and its equivalent, "perfect accuracy," has no meaning in workshop practice, notwithstanding that it is employed loosely. No competent mechanician would guarantee the absolute accuracy of any piece of work, neither is there any instrument in existence which would be capable of checking or measuring without error. Instead, therefore, of using the old phrase, "perfectly true," and its equivalent, error is admitted, and its amount stated. This is really the basis of the numerous limit gauges that are so prominent a feature of present-day manufacture, and which are of recent growth. If, for instance, an error of $\frac{1}{1000}$ of an inch is considered permissible in a given class of product, as not being detrimental to its proper fitting, or to the operation of the mechanism of which it forms a part, then a limit gauge is made to embody that amount of error, and if the piece of work passes that gauge it is accurate enough for its purpose.

But though admitting the impossibility of securing absolute accuracy in mechanical production, nearer approximations to that ideal are being constantly made. This is only practicable by the gradual elimination of hand work, and the substitution of the work of some special machines, or machine adjuncts for it, the latter in the form of jigs.

The automatic screw machines have been very influential in the production of approximately accurate and uniform results. This is not so much due to these machines themselves as to the adjuncts which are fitted to them in the form of box tools. The latter in many cases fulfil the function of gauges as well as cutters, either by their hollow form in some cases, or by the insertion of steady pieces in opposition to the cutters. But the grinding machine is fast becoming the principal instrument by means of which these results are achieved, since it is possible to grind not only with extreme precision, but also to predetermined dimensions within highly refined micrometric limits, a triumph which cannot (some few special cases excepted, as scraping) be achieved by hand work, and then only at a greatly enhanced cost. If a gauge has to be corrected finely it is ground, and if a screw requires correction it must be ground; so must spindles, bushes, cutters, and much besides. *See* **Grinding Machines,** &c.

Three things render perfect accuracy impossible of attainment, or of retention, if obtained by chance. These are changes due to temperature, the flexure of bodies, and the internal changes which take place even in the most homogeneous materials. In doing the finest work, uniform temperature in the workroom has to be maintained. Even the approach of a person

from without effects a measurable change in dimensions. Flexure of screws and rods, as also that of standard bars, results in measurements different from those obtained if such flexure is prevented. Internal changes are only minimised by laying pieces aside after roughing out, for several weeks, or months, before finally finishing them. In proportion to the degree of accuracy sought does the importance of attention to these matters become more emphatic. The subject is a vast one, much information concerning which will be found under various heads in this work. The object of the present article is to denote the border line which separates the practicable from the impossible, the commercial ideal from the theoretical objective. Though the present tendency is all in favour of higher accuracy, and though it makes more exacting demands on the products of machinery, the important point to note is that it proceeds within well understood and defined limits, which vary with different classes of production. In the highest stages, these limits occasionally range as fine as $\frac{1}{10000}$ part of an inch, but these are far exceeded in the preparation of line standards for measurement. These exist within about 25 millionths of an inch of perfect accuracy on a yard length, and at a definite temperature. For commercial engineering, limits lie within about $\frac{1}{100}$ inch to $\frac{1}{1000}$ inch of exact dimensions.

One of the most difficult objects to produce with close approximation to truth is a long screw. Yet these are regularly made commercially, and without grinding, within $\frac{1}{100}$ inch on a length of 6 feet, a truly remarkable achievement. These limits are extremely coarse by comparison with those which are demanded and are obtained in master screws used for dividing purposes. Accuracy, therefore, is never absolute, but relatively approximate only, and variable within a very large range.

Absolute Pressure. — Steam pressure reckoned from the point of perfect vacuum, instead of above atmospheric pressure. As the steam gauge gives the pressure above the atmosphere, the absolute pressure equals that shown by the gauge, plus that of the atmosphere.

Absolute Strength. — The ultimate or breaking strength of a material. It is necessary to know this as a basis on which to apportion the working strength. The ratio between the two is the factor of safety for that material, when employed under given conditions.

The determination of the absolute strength of materials is not now disposed of in so summary a fashion as it was at one time. For dead loads and simple crushing tests the breaking strength is not much complicated by other considerations. But when live loads, and bending or tensile or torsional stresses are in question, the effect of repeated stresses is to lower the breaking strength. *See* **Fatigue of Materials.**

The results of tests of absolute strength have often been vitiated, with resulting serious discrepancies in the results given by different experimentalists, by employing unsuitable test specimens. Small selected pieces, whether of wood or metal, are not fairly representative of the more massive pieces used for constructive purposes, and which generally possess some faulty portions. *See* **Test Specimens.**

The breaking strength of the elastic materials, as mild steel and wrought iron, may be artificially raised by raising the elastic limit, but at the expense of ductility. *See* **Elastic Limit.** In few cases now, with the exception of loads which act by crushing absolutely, is the breaking strength considered apart from the elastic strength. The latter is fully recognised as being of equal importance with the former as essential to safety. And as the maximum of each cannot co-exist, the quality of absolute strength has generally lost some of the estimation in which it was formerly held.

Absolute Temperature.—*See* **Absolute Zero.**

Absolute Units.—These are so termed because they are based on natural laws, as distinguished from units which have an artificial basis of convenience merely. Geometrical, mechanical, and electrical units belong to the latter group, but the units of heat, of time, of gravity are of natural origin. All the recognised units, absolute and derived, will be found treated under their numerous headings.

Absolute Zero.—This is a temperature

which is fixed theoretically at 461 degrees below ordinary zero, or 493 below freezing by the Fahrenheit thermometer, or in the Centigrade it is 274 below ordinary zero. Ordinary temperatures can therefore be converted into absolute by adding 461 to ordinary zero in the Fahrenheit system, and 274 to that in the Centigrade. Regnault assigned a difference in gaseous volume of ·3665 between 32 degrees Fahr. and 212 degrees Fahr. which would give 459 below zero Fahrenheit, or 273 below in the Centigrade.

The reasoning by which the temperature of absolute zero is fixed is as follows:—Pure gases expand at a uniform rate with increase of temperature when under constant pressure. Also if the volume is maintained constant, the pressure exerted by a given weight of gas is directly proportional to the change in temperature, provided only that the point of liquefaction is not approached. Further, a pure gas at a temperature of 32 degrees Fahr. expands $\frac{1}{461}$ part of its volume for each degree in rise of temperature. Hence the inference is drawn that if the temperature were reduced to 461 degrees below zero Fahr., pure gases would cease to exist as gases. Though the reasoning adopted seems conclusive, yet no such temperature has yet been attained, and probably never will be. Absolute zero is used in calculations on the expansion and contraction of gases under constant load, constant volume, or both varying, for which formulæ and co-efficients of expansion are given in text books, based on the law that the product of the pressure and volume of any gas is proportional to the absolute temperature.

Professor Dewar has reached the lowest temperature yet recorded—that of solid hydrogen. Liquid hydrogen boils at -422 degrees Fahr. at ordinary atmospheric pressure. Reduction of pressure by an air pump lowered the temperature to -432 degrees, at which the liquid became solid. The liquid is the lightest known, its density being only one-fourteenth that of water. The only solid which will float in it is the pith of wood.

Absorbent Bodies.—*See* **Absorption.**

Absorption.—Denotes in general terms the capacity of a body for receiving and retaining anything from without. The principal absorbent bodies which are involved in practical engineering are metals and timber. These are susceptible to the influence of heat and moisture. The capacity of a body for the absorption of heat depends on the nature of the material and on the character of its surfaces, whether dull, and coated, or polished. It is equivalent also to radiating power. The higher the polish on metals, the lower is their capacity both for absorption, and radiation. The reflecting power is the complement of the absorbing power of a material. Since a highly polished vessel reflects well, it radiates badly, and therefore retains heat readily.

The absorption of moisture has reference chiefly to timber which is preserved by impregnating it with substances which occupy the pores. *See* **Metals, Timber—Preservation of.**

The absorption by a body of other substances meets the engineer and builder at all points, because the weight of absorbent bodies is that of their weight either dry, or plus some other substance. The weight of wet wood is often twice that of dry, and the weight of some sandstones and of bricks is greater when wet than dry. Any body which has interstices is absorbent, and to get at the weight of such a substance, a specimen piece must be taken, and weighed as a sample.

The term also denotes the absorption of power by a friction brake.

Absorption Dynamometer.—*See* **Brake Dynamometer.**

Abutment.—Generally applied to the foundation and superstructure which receives the end thrust or pressure of a single arched bridge, or of the end arches. *See* **Arch, Bridge.** The term is also applied to many portions of mechanism which receive and absorb the reactionary forces of pressures, or movements, often therefore termed abutment pieces.

Abutting Joint.—A joint, the members of which meet by their ends, as distinguished from those which are in contact by their sides or edges. It is generally employed in the contracted term of "butt joint." Abutting joints in timber are united by tenons, mortices, by iron straps, or by strap bolts. Similar joints in

metal work are secured by riveted tees, by butt straps, by fish plates, and by various bracketings described under their suitable headings.

Acacia.—Includes numerous species of the sub-order *Mimosæ*, of the order *Leguminosæ*. Sp. gr., 0·82; weight of a cubic foot, 51 lb. Acacia wood grows chiefly in America, and is used there for many outdoor purposes. It is equal to oak in durability, and there are very few purposes for which it might not be used, but it is too small in size and scarcely plentiful enough to occupy a very important place in the list of hardwoods. It is used in shipbuilding and in cabinetmaking, and for trenails for railway chairs. These are the true species of acacia. The one in commonest use is not recognised as true acacia. In America it is known as the wood of the locust tree. The common acacia is occasionally used for cogging toothed wheels.

Accelerated Circulation.—The circulation of water in a steam boiler which is in excess of a merely free or good natural circulation. It is applied specifically to certain classes of water-tube boilers.

The best kind of accelerated circulation in ordinary boilers is afforded by the well-known Galloway tubes, which are placed at a vertical angle across the furnace tubes of Lancashire and Cornish boilers, the effect of which is to produce an accelerated upward current of water and steam.

In water-tube boilers, accelerated circulation is distinguished from free circulation on the one hand, and limited circulation on the other. It resembles the action produced by the Galloway tubes in respect of the maintenance of a current of steam and water at a much higher velocity than is obtainable by merely free circulation. This is produced by such a disposition of tubes that a continuous circuit is maintained between tubes carrying steam from below upwards, and tubes returning the water from the upper to the lower reservoirs. The subject may be treated mathematically, but the best boilers are the result of experimental working.

The history of modern boilers with accelerated circulation began with a design by M. Sochet, who was followed by Commander Du Temple, who made the first boiler of this kind which was tried on launches and torpedo boats (1878). This boiler was improved by M. Normand and M. Guyot. Subsequently M. D'Allest, Mr Thornycroft, Mr Mosher, Mr Yarrow, Mr Blechynden, and others have constructed boilers with the same object in view.

In the Du Temple boiler, which is still made in the main after the original model, two small water chambers at the sides of the furnace are connected to the steam drum above by generating tubes which are bent backwards and forwards, in loops, four times, finally discharging into the drum below water level. Large external downtakes at front and back return the water from the drum to the water chambers below, completing the circulation.

On this early design many improvements have been effected. The circulation in the original sinuous tubes of small size, of only about ½ inch in diameter, the main lengths of which departed but slightly from the horizontal, were subject to accumulations of deposit, which not only interfered with the circulation, but resulted in their burning out. The main improvements only need be noted here. They consist principally in the use of larger tubes, and the simplification of their bends. They are at present made of about 1 inch bore (1·38 inches outside). In one type the tubes are bent twice only, instead of four times. Another improvement consists in an arrangement of the tubes by which a partial baffle is formed to the gases ascending from the furnace. Later still and at present the tubes lay closely, making a wall round the fire, so causing the flame and hot gases to return from one end of the boiler to the other before escaping into the funnel.

In the boiler as improved by M. Guyot, the tubes have a single curve only of large radius in their length, by which bends are avoided, without the sacrifice of elasticity. M. Normand retained the folded design, but lessened the number of folds, retaining as much only as he deemed necessary to allow for expansive movements. As this alteration lessens heating surface, the number is increased to afford compensation. He also adopted double-ended boilers

of this type for large ships. Boilers with accelerated circulation soon displaced the locomotive type on torpedo boats.

The two principal types of boilers in Britain are the **Thornycroft Boiler** and the **Yarrow Boiler**, described and illustrated under those heads. The leading characteristics of the first are that the generating tubes are curved, and arranged closely to form a complete arch over the fire-grate, and that they enter the steam drum above instead of below the water level. A large heating surface is thus secured. The design is varied, though similar in principle, for large vessels. The Yarrow boiler is almost a class by itself, since the tubes are all straight, running diagonally from the water chambers below to the drum above. The objection to these straight tubes, which appears to be more theoretical than based on fact, is their want of elasticity. Neither are there any external downtakes, the circulation therefore takes place in the tubes only. The **Blechynden Boiler** resembles the Yarrow in possessing straight tubes, and in the absence of downtakes apart from the tubes. The **Fleming and Ferguson Boiler** differs in several important respects from other types, and receives a separate description. Several other boilers are made for accelerated circulation, including one by Mr Seaton, the Reed, the White, and the D'Allest.

Acceleration is the rate of increase of velocity of a body. Thus, if at a certain moment a body is moving at the rate of 20 feet per second, and 1 second later it is moving at 25 feet per second, the acceleration is 5 feet per second in each second. When the velocity increases by equal amounts in equal intervals of time, the acceleration is spoken of as *uniform*, as opposed to *variable* acceleration. There are two systems of units used—the English F.P.S. (foot-pound-second) system, and the metric C.G.S. (centimetre-gramme-second) system.

A body moving with uniform acceleration may be considered either as starting from rest, or with an initial velocity. Taking first the case of a body moving with uniform acceleration from rest. If the letter A represents the acceleration of a body starting from rest, at the end of 1 unit of time the velocity, V, will be represented by A; after 2 units of time $V = 2A$, and after any number of units of time —conveniently represented by the letter T— the velocity V will equal $A \times T$, or, putting it in the form of an equation, $V = AT$. If, however, the body starts with an initial velocity V_1, then the velocity at the end of the interval will equal $V_1 + AT$, or $V = V_1 + AT$.

Again it is clear that in a body moving with uniform velocity, "distance traversed = velocity × time," which may be put in the form of an equation $S = VT$, where S denotes the distance traversed, and V and T the velocity, (in feet), and time, (in seconds), respectively. But with accelerated motion the velocity is *variable*, and this equation does not apply. It is necessary to know the mean velocity during the time T. This will be found by taking the **Arithmetical Mean** between the initial and final velocities, which will be $\frac{V_1 + V_2}{2}$. V_1 = initial velocity; V_2 = final velocity. The distance traversed, S, will then be $S = \frac{V_1 + V_2}{2} T$. But if the body starts from rest, or comes to rest at the end of the acceleration, V_1 and V_2 will both equal O, and the equation will be written $S = \frac{V}{2} T$. Taking this and the equation $V = AT$, and multiplying the two left hand and the two right hand sides together, we get $S = \frac{A}{2} T^2$. By eliminating T we also obtain $V^2 = 2AS$.

Thus for a body starting from rest and moving with uniformly accelerated motion we have the four important equations :—

$$V = AT \qquad (1)$$

$$S = \frac{V}{2} T \qquad (2)$$

$$S = \frac{A}{2} T^2 \qquad (3)$$

$$V^2 = 2AS \qquad (4)$$

where T = the time in seconds; V = the velocity in feet per second at end of time T; S = space or distance passed over in time T; A = acceleration in feet per second.

With the help of these four equations any problem involving these quantities may be worked out.

For example: A train starting from a station acquires a velocity of 60 miles an hour 8 minutes later. What distance will it have traversed in that time? Here we are given velocity V, time T, and have to find distance or space S. Evidently we must use the second equation. 60 miles an hour = 88 feet per second. Therefore—

$$S = \frac{88 \times 480 \text{ (secs.)}}{2} = 21120 \text{ feet} = 3{\cdot}1 \text{ miles.}$$

In the case of bodies with uniformly accelerated motion and with an initial velocity we have already seen that

$$S = \frac{V_1 + V_2}{2} T \qquad (5)$$

We have also seen that

$$V = V_1 + AT \qquad (6)$$

and by substituting this value of V in equation (5), we get

$$S = V_1 T + \frac{A}{2} T^2 \qquad (7)$$

By multiplication we obtain from the same equations the formula $2AS = V_2^2 - V_1^2$. Dividing each side by 2A we get

$$S = \frac{V_2^2 - V_1^2}{2A} \qquad (8)$$

From equation (6), $V_1 = V_2 - AT$, and by substituting this value of V_1 in equation (5) we get

$$S = V_2 T - \frac{A}{2} T^2 \qquad (9)$$

This comprehensive set of equations will be sufficient to work out any problem dealing with uniformly accelerated motion with an initial velocity.

The case of a body falling under the influence of gravity is identical with the case of a body moving with uniform acceleration under the influence of force. Thus we have only to substitute H for S, (height for distance or space), and G for A, (gravity for acceleration). Experiments have shown that the acceleration of an unresisted falling body is uniform although it varies in different parts of the world, being greatest at the Poles, least at the Equator; greater at the sea level than on the summit of a mountain. In round numbers we say that the acceleration of a body dropped from a height is 32 feet per second per second. This therefore will be the value of G whenever it occurs. We get then the following formula for the solution of questions dealing with bodies falling vertically.

G = acceleration due to gravity = 32 feet per second; H = height in feet from which body falls; V = acquired velocity at end of T seconds; T = time in seconds.

$$V = GT \qquad V = \sqrt{2GH}$$

$$H = \frac{VT}{2} \qquad H = \frac{GT^2}{2}$$

$$T = \sqrt{\frac{2H}{G}} \qquad T = \frac{2H}{V}$$

Examples: A body falling from the top of a structure reaches the ground in 3 seconds. How high is the structure? Height, H, is here the required quantity, and we are given time T, and gravity G. Taking the formula $H = \frac{GT^2}{2}$ and substituting the given quantities for letters, we get $H = \frac{32 \times 3^2}{2}$ = 144 feet = the required height.

A brick falls from the top of a factory chimney 100 feet high. What velocity will it attain when it reaches the ground? Taking the equation $V = \sqrt{2GH}$ and substituting the given quantity, we get $V = \sqrt{2G \times 100}$ or $V = \sqrt{64 \times 100} = 80$. Thus the brick will have attained a velocity of 80 feet per second when it reaches the ground.

Acceleration, C.G.S. Unit of.—The centimetre-gramme-second unit of acceleration is that of a body of which the velocity increases 1 centimetre per second.

Accident Crane. — *See* **Breakdown Crane.**

Accidents, Prevention of.—The immense importance of this subject may be gauged by the Annual Reports of the Chief Inspector of Factories. The last returns give the following:

All Reported Accidents, 1903.

Age and Sex.	Fatal Accidents.	Increase or Decrease.		Non-Fatal Accidents.	Increase or Decrease.		Total Accidents.
		Number.	Per Cent.		Number.	Per Cent.	
Males - - -	1,031	− 35	− 3·3	86,045	+ 2,637	+ 3·2	87,076
Females - - -	16	− 28	− 63·6	5,508	− 329	− 5·6	5,524
Total - -	1,047	− 63	− 5·7	91,553	+ 2,308	+ 2·6	92,600
Adults - - -	953	− 39	− 3·9	77,050	+ 2,323	+ 3·0	78,003
Young Persons -	92	− 23	− 20·0	14,270	+ 45	+ 0·3	14,362
Children - -	2	− 1	− 33·3	233	− 60	− 20·5	235

Accidents Reported to Certifying Surgeons, 1903.

Degree of Injury.	Accidents.
Fatal - - - - - - -	1,047
Loss of hand or arm - - - -	151
Loss of part of hand - - - -	3,072
Loss of part of leg or foot - - -	149
Fracture - - - - - - -	1,511
Loss of sight - - - - - -	59
Injuries to head or face - - -	3,375
Burns and scalds - - - -	3,028
Other injuries - - - - - -	18,117
Total - - - - -	30,509
Accidents reported to inspectors only	62,091
All reported accidents - - - -	92,600

It must be remembered too that only the accidents of a more or less serious character which are reported to the inspectors and surgeons are included. This last, moreover, does not include casualties in deep mines and quarries, which form another group, together making up a vast total of the martyrdom of labour.

By far the largest proportion of accidents is placed to the charge of miscellaneous "machinery moved by power," being 25,400, out of a total of 92,600. Lifting tackle claims the heaviest toll of all classified machinery, having caused 98 fatal, and 2,633 non-fatal accidents in the year.

A few years ago the practice of fencing and guarding machinery was practically non-existent. Not till the passing of the Workmen's Compensation Act of 1899 did the matter begin to assume much importance. Even to-day there is a great deal of dangerous mechanism which is either unguarded, or else inefficiently protected. Frequently the greatest carelessness exists on the part of the workpeople, especially when working by the piece, who will run risks rather than occupy a few minutes in replacing a guard.

The parts of machines and motors which are most liable to cause accidents are toothed gears, belts and their pulleys, ropes and their pulleys, shafting, and moving couplings, rods and arms, fly-wheels, emery wheels, circular saws, machine knives, rolls, crane chains, and lifts. All these are responsible for mutilation and death every year.

The methods of fencing and guarding must needs be varied widely to suit different mechanisms and operations. They must be efficient, in the judgment of the factory inspector. They should not interfere with the operation, or proper observation of the machine, and if made removable, they must be capable of ready replacement. The nature of the material employed for guards depends on circumstances. Latterly many firms have included the fitting of proper and neat guards to the dangerous sections of their machines, but that is as yet a practice more honoured in the breach than in the observance. In Germany the practice is nearly universal. Manufacturers are better able to fit such guards than purchasers and

users, because the cost of making patterns for castings, or stamps for sheet steel, being spread over large numbers, reduces the expense for a single article. Besides, the neatest and best guard can be studied more thoroughly in a big manufacturing scheme than in isolated instances. Some firms understand this, and fit neat and efficient guards to cover all dangerous sections.

The materials used in fencing are timber, cast iron, sheet metal, bars, rods, and wire. In some cases there is little room for choice, in others the choice lies between three or four. Timber is least suitable of all, partly because it absorbs grease, chiefly because it prevents getting at the parts enclosed, for examination or lubrication. Its most suitable sphere is in fencing round belts that come up, or pass down right through floors, or that come down to pulleys situated at about the floor level, or a little higher, as in the case in many machines used in wood-working factories, in boiler shops, and others. Match-boarding is the material used.

But the same protection can often be afforded by guards of wire netting, which are cleaner and neater, and which do not obstruct light from the pulleys, or bearings enclosed. Such netting is utilised largely for other classes of protection.

Engines generally have their moving parts protected by horizontal rods or rails carried in pillars. It is well in addition to this to enclose the lower portion of the area with wire netting in order to prevent risk of anything rolling along and getting entangled with the moving parts. In some portions of machinery, such as connecting rod ends, and in bearings lying behind fly-wheels, **Automatic Lubrication** is adopted to avoid the necessity for the attendant to take any risks. The protection of boiler gauge glasses is necessary in case of their fracture.

The guarding of the belts of machine tools can only be partially done. It cannot be applied on the stepped cones of lathes where the belt has to be constantly shifted. It can be, when the drive is on a single pulley, as in some high speed drilling and milling machines, and as in the belt pulleys of fans for blowing and exhausting. But belt pulleys must be guarded whenever possible, and this is done on machines by fixing a light removable or hinged guard of wire netting round, which offers no difficulty in the way of belt changing. If pulleys and belts are only partially guarded, it must always be done on the ingoing side, where alone there is risk of the hands being drawn in. Pulley arms are a source of danger, and so are collars with heads of set screws projecting. Even on line and countershafts these screw heads should be condemned in collars and couplings.

Toothed gears should always be wholly encased, either with light cast-iron hoods, or with stamped or bent hoods of sheet steel, or with wire netting on a stiff framing. In many cases holes can be left for lubrication, and wire netting does not interfere with this. If protection is only partial, the ingoing side must be covered. Particular cases of gears are those of bevels, and of change wheels. Castings make the best and neatest cover for the first, and wire netting for the second. The latter must be readily removable to permit of changing the wheels. As change wheels are slow running, there is less need to cover these than the high speed wheels of the back gears, both of lathes, and drilling, and other machines.

Many minor accidents occur in lathes due to the continued retention of the bad form of lathe carrier generally used, in spite of the fact that there are better ones to be had. When a man is working up close to the headstock, he needs to keep an eye to the carrier as well as to his work.

A frequent cause of minor accidents is due to chips, especially from brass, getting into the eyes, and the "eye doctor" is consequently frequently called in to remove the offending stuff with a bit of pointed stick. This is sometimes guarded against by wearing goggles, but generally a leather guard is stuck above the nose of the tool.

Many gear covers can be made to serve a double purpose, that of protection, and that of an oil catcher, or an oil bath. An enclosed hood will prevent oil from flying about, and in the case of worm, spur, or bevel gears it can be used to lubricate the gears, as is now done in travelling cranes, and in the feed gear boxes of many machine tools.

Rolls, as used by boiler-makers, laundresses, and in textile processes, have been responsible

for many crushed hands and arms. It is difficult to guard these without interfering with their operations. The only effectual way is to bring a guard down as close as possible to the entrance of the rolls, so that a finger cannot be inserted. The revolving knives of wood-planing machines create a danger of a similar character.

Circular saws were formerly never guarded, but now they are generally protected. Many guards, however, are still without riving knives at the back. Any one who has worked saws knows how stuff is liable to be lifted up at the back, and sent flying towards the front, and perhaps drawing in the hands of the attendant stationed at the rear. The riving knife practically extinguishes risk of such accidents. *See* **Saw Guards.**

Emery wheels are best guarded with sheet-iron hoods, though perhaps the larger number still have hoods of cast iron. The objection to the latter is that a fracture of the wheel might perhaps fracture the guard also, and send the fragments flying. A flexible form of guard is used on many Continental grinders. The sides of a wheel should be protected as well as the periphery. The best modern wheels are rendered practically secure against a disastrous fracture by the fitting of the washers, which are curved to grip curved faces on the wheel, so probably retaining broken pieces. Some makers, too, test their wheels beyond the proper running speed, to give them a chance to fracture before sending them out. *See* **Guards** for illustrations.

The best protection for lifts is a subject on which there is no unanimity of opinion. A useful safety device is the bar gripper, that can be used in connection with an automatic catch, which latches the gates and prevents them from being opened except when at the proper floor level.

Even where machinery is properly fenced, many accidents occur through heavy articles falling on men's limbs, or through revolving work flying out of the machines, and from sling chains or ropes breaking, through molten metal running out or splashing, and from scalding water, or steam.

Accidents due to electric shock are now added to those of revolving wheels, shafts, and belts. The best safeguards are, wearing indiarubber gloves, and rubber-soled shoes, which should be worn constantly among electrical machinery, but not used indiscriminately out of doors, absolute cleanliness and dryness being essential to perfect insulation. Live wires must never be handled except with indiarubber gloves, nor in case of accident must they be cut except with nippers having insulated handles.

When an accident occurs, the rescuer or rescuers have to exercise great care to avoid receiving shock from the sufferer. In the absence of gloves or shoes, insulation may be secured by standing on an indiarubber mat. Failing this, dry boarding or a heap of dry clothes will supply partial insulation, and the hands must be wrapped in dry clothing before attempting a rescue. Anything damp, whether the hands or clothing, becomes a conducting medium. A piece of dry wood may be used to remove a wire from contact with a person.

The foregoing remarks cover only one aspect of the subject. They do not touch the broad questions which concern the safety of engines, shafting, main belts, and pulleys, the safety of cranes, and crane tracks, electrical conductors, &c.

The prevention of accidents is a subject in which these, and other matters are included. It begins with the designs of mechanisms. In it is involved the prevention of fracture, both under normal and abnormal stresses, by imparting strength sufficient, within the elastic limit, the selection of a suitable factor of safety, the making provision in some cases for ready means of examination and repairs. Again, in many mechanisms provision is embodied for preventing accidents due to "racing," or of a wrong movement. Governors, breaking pieces, stop, and throw-out motions, yielding springs, safety brakes, and grips, relief valves, safety valves, duplication of valves, are the principal among these.

In the working of machinery, in which movements have to be effected at the will of the hands, many safety appliances exist. Belt shippers are among the most familiar of these. Many hundreds have suffered loss of life or limb in the attempt to throw belts on and off their pulleys by hand, either by being caught between the belt and its pulley, or by projecting keys, or set screws, &c., catching in the clothing at the time. A fruitful source of accident also is the

loose clothing worn by factory hands, loose sleeves especially. Many again have occurred in consequence of starting engines without first making sure that no one is working among the machinery, or on the other hand through lack of means of stopping them at once when an accident has occurred. Cranes are frequent sources of accident when handled by unskilful and inexperienced men. So are steam boilers.

An ambulance should find a place in every engineering works, and ambulance classes might be generally held with advantage, as they are in some firms. Many accidents, not dangerous in themselves, become fatal through lack of intelligent first aid.

Conducive to the prevention of accidents is a set of stringent printed rules, rigidly enforced. None are so careless as the hands, who require to be protected against their own indifference to, and neglect of common precautions; and no excuse of haste or profit should be allowed to interfere with the safety of employees.

The factory inspectors, backed up by the Home Office, are always ready to give information and advice as to the best methods of preventing accidents. There are right and wrong ways of fencing, and the wide experience of the inspectors qualifies them for giving valuable suggestions to owners of machinery.

Accounts—Factory.—The accounts of a big modern factory are very complicated. They tend to become more so, besides which they are sometimes elaborated and involved to an unnecessary extent by what the writer considers a craze for system, which tends to degenerate into red-tapism.

It may be conceded that more elaboration of accounts is required in the present period of predominance of limited liability companies than was necessary in the past, when firms were managed and supervised by their private owners, with the aid of confidential clerks, and fairly permanent old hands. Great changes then rarely occurred in those works, and personal character and interest generally prevented much waste or peculation.

The present ideal is, that no matter how men may come and go, the system remains, and so perfect, that new men can come and readily pick up the threads left by their predecessors. But much more than that is required. It is demanded that in a perfect system the cost of any job shall be readily ascertained in any shop, at any stage of its progress. In many of the older shop systems this has not been the case, but the work has had to be finished before the total costs and the profit or loss could be ascertained even approximately. It is also considered essential that the amount of, and value of any materials, or of work in hand, stock, or order shall be readily ascertained at short notice.

It is further required to ascertain whether men are doing more or less work than at any other periods, a matter which is complicated by the great growth of machine methods. The labour saving due to machines has therefore to be correlated with the mere labour factor, and with the introduction of every new and improved machine and appliance, readjustments become necessary, and prices have to be rearranged. Here too there comes in the question of fair prices, not only for day-work, but for piece-work, and those paid under the bonus, or the premium system.

The accounts of an engineer's factory include the following main heads — Orders, Labour, Materials, Prime Cost, Capital, Profit or Loss.

These may be subdivided broadly as follows:—

1. ORDERS	Order books in office - -	General offices
		Drawing office
		Receiving clerk's office and Stores
	Orders to works	To managers
		To foremen
		To men
		Passing through the shops
2. LABOUR	Skilled and Unskilled	Hours worked
		Time-keeping methods
		Rates of wages, including overtime
		Day-work
		Piece-work
		Bonus-work

<table>
<tr><td>3. MATERIALS</td><td>Materials kept in stock
Materials obtained for orders
Orders for materials
Invoice and receiving book
Periodical stocktaking
Charging materials out
Responsibility for</td></tr>
<tr><td>4. PRIME COST</td><td>Orders, Stock
Materials
Wages
Supervision
General charges
Contingencies
Interest on capital</td></tr>
<tr><td>5. CAPITAL</td><td>Buildings
Plant and machinery
Depreciation
Losses
Income tax
Reserve funds
Assets: The above, also; Patterns; Stores; Work in hand; Patents; Goodwill</td></tr>
<tr><td>6. PROFIT OR LOSS</td><td>A good system of accounts</td></tr>
</table>

1. *Orders.*—These, as we have shown in Table 1, comprise two broad groups, that which is restricted to the offices, and that which concerns the shops.

When an order comes in, a letter and number is allocated to it, the letters going through the alphabet, as the numbers, up to a thousand or sometimes more, swamp the letter. So that an order for, say, a 50-ton crane does not go out into the shops thus, but as B950, or C864, or any number which it happens to appropriate in rotation of the system of order numbers in use. These order numbers go right through the works, accompanying every item of the job from beginning to completion.

In the office group there are three departments in which the order is recorded. There is the general office, from which all instructions emanate, and to which all accounts return. It includes the principals, or general managers; the drawing office; the estimating office, the latter sometimes separate from, or merged in, as a sub-department of the drawing office, the receiving clerk's department; and the stores where materials are received, and whence they are charged out and duly entered in day books and ledgers. The two broad systems in use in the general office, and in the receiving office and stores, are the ordinary methods of book-keeping, and of the recent card systems.

In the drawing office every drawing made, and every requisition for materials got out, is stamped with the order number of the job. The drawings go into the works, the requisitions to the materials clerk, or stores clerk, or clerks. Or they are sent back into the general office to be ordered by a responsible director, or principal. A frequent practice is for the general office to retain the responsibility of getting quotations and discounts for big consignments of material, leaving the stores clerk to order smaller quantities of general goods such as are required to keep the stores suitably supplied. Materials will thus be ordered under two heads, the special, and the general; the first-named by "order numbers" for jobs, the second to be drawn upon and charged as required for special jobs. As work increases in size, the former frequently predominates, as for example in unusually heavy bridge and girder work, and as the proportion of sketch plates increases. But ordinary plates and bars, cast iron, and gun-metal, timber, brass fittings, and so on are kept as common stores.

The orders to the works pass to the general work's manager, and to the heads of departments in the shape of entries in "order books" to each, accompanied with a written or printed specification, when the nature of the work is such as to render it necessary. This is the case when special mixtures of metal, or special tests are inserted, or when methods of tooling, as drilling, or reamering, or limits of accuracy are stated, so that the foreman or manager of a department shall have no excuse for omitting to fulfil the conditions specified, as may be and

often is the excuse if verbal instructions alone are given.

The orders are given by foremen to the men by the numbers accompanying the drawings. Orders are verbal, or they are written on cards, or on slips of printed paper. The advantage of a good card system here is its comprehensiveness. Thus, in giving orders from pattern shop to foundry, the foreman of the former sends with the pattern (stamped with the order number for the job) a printed card, on which he writes the order number, the numbers of castings required off, the number of core boxes if such are included, and any remarks relating to pattern alterations, or which might assist the foreman of the foundry in carrying the work through. The latter again passes the card out with the castings, on completion of the order, along with a moulder's card, or the two may be included in one. The weight of the castings is entered thereon, and goes into the stores, and thence back into the general office to be taken charge of by the time clerk, and used in balancing accounts. All work converges finally to the shipping or despatching department, which in a big factory is a distinct one, or in a smaller one, it is merged in the receiving department.

At every stage the question of costs is involved, which may be now considered under the headings already given.

2. *Labour.*—Labour includes both skilled and unskilled. It comprises all wage-earners from the draughtsmen down to the boys. But as a rule it does not include salaried men, whether in offices or shops, because these do not fluctuate appreciably either in numbers or salaries from year to year. Labour embraces the fluctuating elements, the costs of which go up and down constantly. The salaries properly come under general or standing charges. The leading elements in estimating labour costs are the hours worked, and the rates of wages, including overtime. The methods of payment include that of day-work, piece-work, and that under the premium system.

It is round the wages method of payment for labour that strikes always have, and are always likely to occur. The great and permanent objection to wages is that it does not, and cannot take account of differences in the abilities, energies, output, and value of the product of men. Let us see the manner of its working, first as it affects the accounts of the factory, and second in its relation to other methods of payment.

In the abstract it is a simple system. There are certain hours worked in a factory, and wages rates are fixed at so much per week of so many hours, or at so much per hour, reckoned only on the basis of the normal week; all over that being paid for at higher rates. The amount of time worked by a man is entered up day by day, and given into the time office, and thence taken to the office of the time clerk, or wages payment clerk. The time is also entered against the jobs on which the man has been engaged, sometimes one job only, sometimes several in the course of a day or week. The checks to the workman's time take the form of time checks passed into a box at the time office, or of a time recorder, in connection with the card system, in which the times of entry and of leaving the works are stamped automatically on the card. Time worked on jobs out of doors has to be kept by a man in charge, or by the workmen themselves.

All the normal hours worked are paid for at the normal rate of wages, irrespective of the degree of *intensity* of the labour done. Practically the only way to secure a reasonable return from an entire body of men working on day wages is by the exercise of close and constant supervision on the part of shop managers and foremen.

But outside the usual hours of labour at normal rates there is in all shops at some periods the question of overtime, which is always remunerated at rates above the regular rate of wages, notwithstanding that as a general and nearly constant rule the amount of work done per hour is less in amount, or less efficient than that of the normal day. Both day wages at one rate and overtime wages at another have to be cast up in the wages office, to form the first element in the prime cost of labour.

In most works, in some of the departments, for some classes of product, piece-work rates are adopted. Recently the premium system or bonus system has come to supplement or supplant both piece-work and day wages. Although piece-work introduces a fixed price per job in-

stead of per hour, and the premium system introduces a normal basis price to which a bonus may be added, yet in each, in engineers' shops the day rate of wages is guaranteed. The men stand to lose nothing in any case, but to gain something. In both piece and premium systems the time worked is entered up precisely as for day wages, only the way in which the job is taken is stated on the card or time sheet. It may happen that a man will be doing work on both systems, and both will then be entered up suitably. All these entries have to be sorted out in the office, and either kept on their original cards or transcribed into prime cost books.

The costs of labour thus obtained and sorted out in different ledgers are of less permanent value in engineering works than they are in that now very limited number of industries in which hand labour still predominates. They are of less value in progressive engineers' works than in those where methods and machinery remain nearly stationary from year to year. They are of less value too in the machine shop than they are in the foundry and pattern shop. The reason is that old methods may go on from year to year with scarcely any change, and then the introduction of new ones will render the old wage records absolutely useless for purposes of reference. The installation of turret lathes, the substitution of pneumatic or electric tools for hand work, the introduction of drop forging or of machine moulding will at once reduce some labour costs by from, say, 100 to 1,000 per cent. Labour costs therefore are a very fluctuating item in a modern factory, and they can only be accepted as reliable for work that is done under precisely similar conditions. This explains why fresh estimates have to be worked out for different orders at different periods, even though the jobs may be nearly identical in character.

3. *Materials.*—The next element in prime costs is that of materials. These too are subject to great fluctuations in price, hence the desirability of laying in large stocks when prices are low. This applies chiefly to pig and scrap, copper and tin, plates, bars, and angles. Timber does not fluctuate so much, and this therefore is stored in sufficient quantity only to permit of keeping a well-seasoned stock. Materials involve a good deal of bookkeeping, beginning with a requisition book in which are entered all the materials required for stock or orders. A general receiving book or books is kept at the entrance or entrances to the works, in which everything that comes in is entered, with its weight. These books are taken to the office every day, and their contents transcribed into various ledgers in which a classification is made according to the nature of the materials, and whether they are for stock or orders. These again are compared with the daily invoice books of the general or receiving clerk's office, and cross references are made from one set of books to the other, with paging, usually in red or blue ink.

The materials are stored as most convenient for handling and use. All the small and the valuable stores are kept in a room in charge of a trustworthy storekeeper. But all the heavy raw material, as pig, scrap, plates, bars, angles, timber, &c., are located adjacent to, or in the shops where they have to be used. But in a well-regulated works not a scrap of material can be used without orders given from responsible persons. Whether it be the materials for a bridge, or boiler, or a packet of screws for a pattern, the material is entered up in a book, on a printed slip, or on a card, against the order number, and to the number of the man who has the job, or the chargeman of the job. The case stands on a different footing in pig, scrap, sand, plumbago, oil, and similar materials which are for the common use of a shop. They cannot often be entered in this way. But the daily or weekly consumption of the shop is entered in the books, and this affords a periodical check against the total stores, the material used subtracted from the material originally stored, enabling the quantity in stock to be ascertained approximately at any given period.

A second check is that of the entries of materials used on jobs, as weight of metal in castings, amount of timber used in patterns, or by the carpenters. Where this cannot be done, as in the case of sand, plumbago, oil, waste, &c., such go into a general charges book as a subdivision of materials.

These elements, labour, and materials are the

chief items in making up prime costs, to which the remuneration of capital has to be added, to be considered presently.

4. *Prime Cost.*—Prime cost includes that of two great classes of work—orders and stock. In each of these are comprised wages, materials, cost of supervision, general charges, contingencies, and interest on capital.

With regard to orders and stock it is necessary to charge these in separate ledgers, to separate order numbers, and to transfer portions of stock to orders when wanted. Stock affords an economical method of production in quantity, lessening the prime cost per piece by comparison with the cost of single pieces, or of small numbers of pieces if done for their orders, so that the stock prices charged over, and the order prices, are taken in making up the prime cost of a job.

The cost of supervision is that of managers and foremen. Under general charges a great deal is included, both in materials and men. It may include clerks, gatekeepers, the amount drawn by the principals weekly from the firm, travelling expenses, agents, advertisements, rates and taxes, petty cash, besides some portions of materials for common use in every shop. Separate accounts are kept of all these in separate books, but the sums total can be added up at stated intervals, and an average obtained as a basis for general charges for a given period, say six months, or a year to come, to be divided *pro rata* on every order that goes through the works.

Contingencies are a charge on estimates, added to estimated prime cost. Interest on capital is also added, and this brings us to the question of capital sunk in a works.

5. *Capital.*—In estimating capital, the following items have to be considered. The buildings, the plant, and machines, depreciation, losses, income tax, reserve funds, assets, which include buildings, plant, and machinery, and drawings, patterns, tools, stores in hand, patents, goodwill. It is easy to see how much of detail these matters open up, some of which will be found treated under their suitable headings. Capital charges become very complicated; so much so, that firms are often the best judges as to the amounts to be debited under the several headings here given. As far as the present article is concerned, the point to emphasise is that every item must be taken separately, and kept as a separate account, and each must be made the subject of a rigid valuation at least once a year. A term of years is too long for a safe basis for these, so rapidly do conditions change at certain periods.

Depreciation is another general charge on capital, but one which is usually kept distinct, and properly apportioned in the work of certain shops alone. Thus for example, the greatest depreciation occurs in the shops where most machinery is used, and it is not fair to load, say, forgings or patterns with depreciation charges of lathes, planing, milling, and other machine tools. Great differences of opinion and practice exists in regard to the percentage of depreciation permissible. A much larger sum is now allowed than was the case a few years ago. A large special reserve fund has to be set aside from each year's profit for this item.

6. *Profit and Loss.*—When all the foregoing are collated and balanced, then a true profit or loss account is obtainable. A good system of accounts is absolutely essential to this result, and one which distinguishes between the different shops. Foundry costs are quite distinct as far as labour and materials are concerned from those of the turnery and machine shop; thus each shop must be rated apart from every other. This is not always done.

The accounts of a large firm of engineers are therefore akin to a scientific analysis. A large amount of bookkeeping, and a big staff of clerks are essential. A far greater amount of attention is given to the subject now than formerly. It pays, because firms are able to detect weak points in their system of manufacture, and remedy them. It is most desirable that a firm should be able to ascertain its exact standing at any period, and this is only possible by the adoption of a very complete system of account keeping.

Accumulated Work.—By accumulated work is meant the work, power, or energy stored up in a body in virtue of its motion. An example is seen in a shell fired from a gun, for in piercing wood or armour plate it performs work, overcoming great resistance. A pile-

driver also is an example of energy or capacity for work in virtue of the velocity acquired by the monkey. The amount of accumulated work in a moving body may be calculated in **Foot Pounds** if the mass (or weight) and velocity be known.

Foot pounds of stored work

$$= \frac{\text{weight} \times (\text{velocity})^2}{64}.$$

$$\text{Or, accumulated work} = \frac{WV^2}{2G}.$$

Where W = weight in pounds, V = the velocity in feet per second, and G the influence of gravity which may be taken as 32, or 32·2 more exactly. Example: A train travelling 60 miles an hour and weighing 240 tons is suddenly disconnected from the locomotive. What amount of work is stored up in the train due to its velocity? 60 miles per hour are equal to 88 feet per second, and 240 tons are equal to 240 x 2240 pounds. Substituting these quantities in the formula we get—

$$\text{Accumulated work} = \frac{240 \times 2240 \times 88 \times 88}{64} =$$

65,049,600 foot pounds.

The accumulated work in the rim of a fly-wheel is equivalent to that of a falling body of a corresponding mass and velocity. The mean diameter of the rim is usually taken as the radius of gyration, and the weight of the arms is neglected.

Accumulator, Electric.—*See* **Storage Battery.**

Accumulator, Hydraulic.—This device is the equivalent of a natural head of water, and it affords an artificial means of producing a statical pressure similar to that of the natural head. The accumulator has the advantage over the head in the fact that the pressure is under control. It was an early invention of the late Lord Armstrong.

Accumulators are of two main types, the more common, or direct form, and the inverted. The difference is, that in the first the ram rises vertically in its cylinder, while in the second, the cylinder slides on the ram. There are also two sub-types, the "weight case" and the "ring weight." In the first, used where space is ample, a cylindrical casing of riveted plates is loaded with any heavy materials at hand, as slag or stones; in the second, employed where space is limited, segmental rings of cast iron are carried on a bottom ring. Besides these, there are

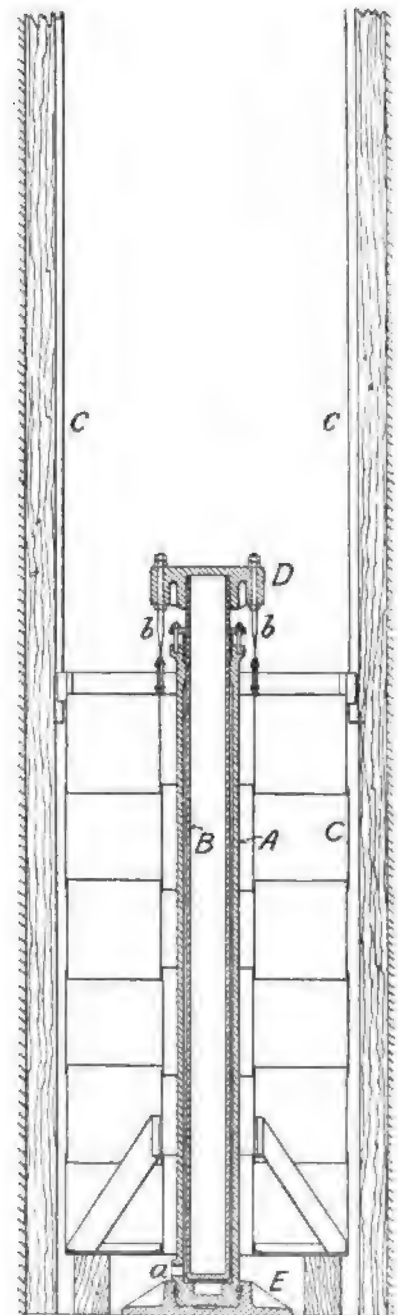

Fig. 1.—Weight Case Accumulator, with Guides.

accumulators suitable for varying pressures; and the differential accumulator, or intensifier, designed to supply pressures higher than those which the machine is directly charged with. These designs are illustrated in succeeding figures.

Fig. 1 shows a weight case accumulator. A is the cylinder, B the ram, C the weight case, D the crosshead. The cylinder has a solid end which is stepped into a base plate E; *a* is the water opening, for inlet and outlet. The ram B fits at the upper end of the cylinder only, in an internal belt and gland, bored to suit the turned ram. The crosshead D affords the means of making a connection between the ram and the weight case C, through the sling bolts, *b*, *b*, attached to the inner tube of the weight case, and having some capacity for adjustment. The inner tube and outer casing are connected with radial stays, and radial gussets, and angles stiffen the bottom part. Angle-iron guides, *c*, *c*, steady the vertical movement of the accumulator. Fig. 2 illustrates another weight case design, having a base plate supported with tension rods. It is shown loaded with broken stone.

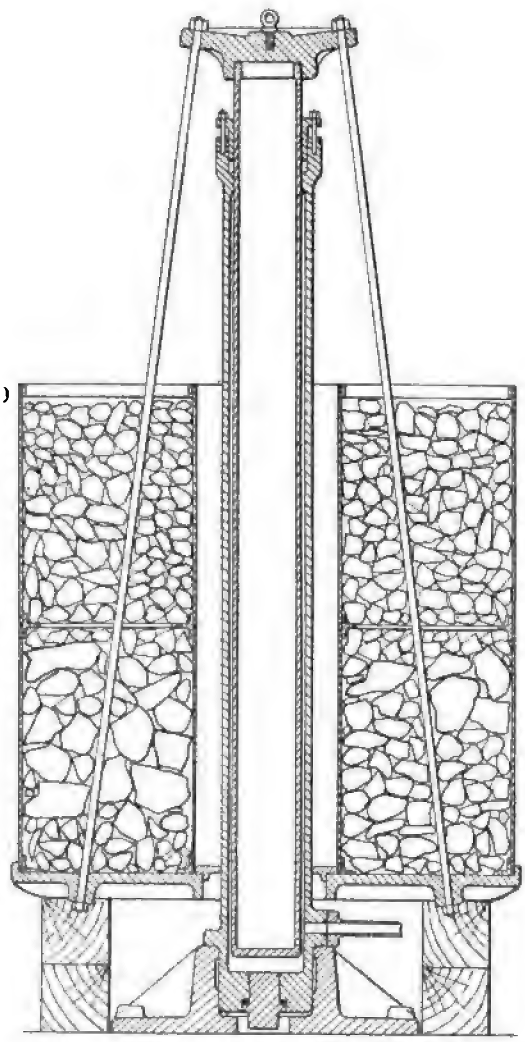

Fig. 2.—Weight Case Accumulator.

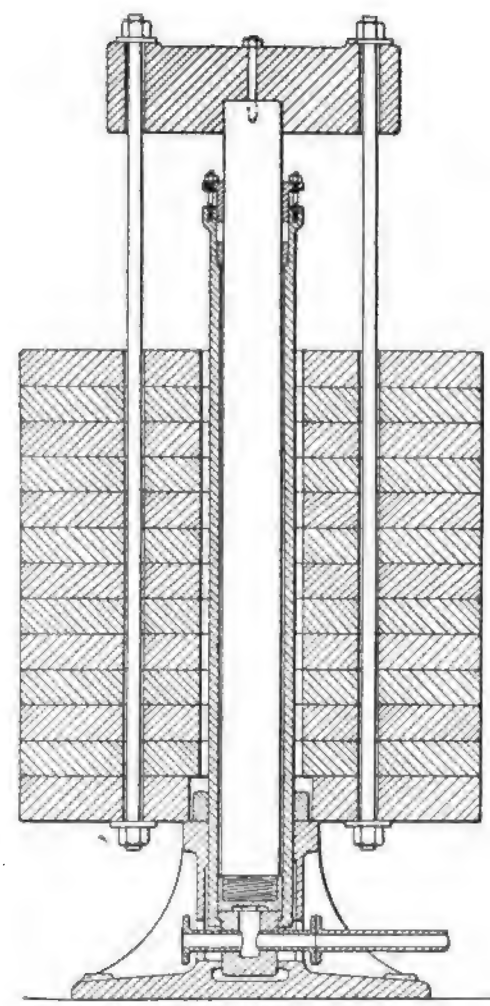

Fig. 3.—Weight Ring Accumulator.

In making weight cases it is usual to allow about 15 cubic feet of capacity for every ton of

material to be loaded in. The dimensions given or required are diameter of ram, stroke of ram,

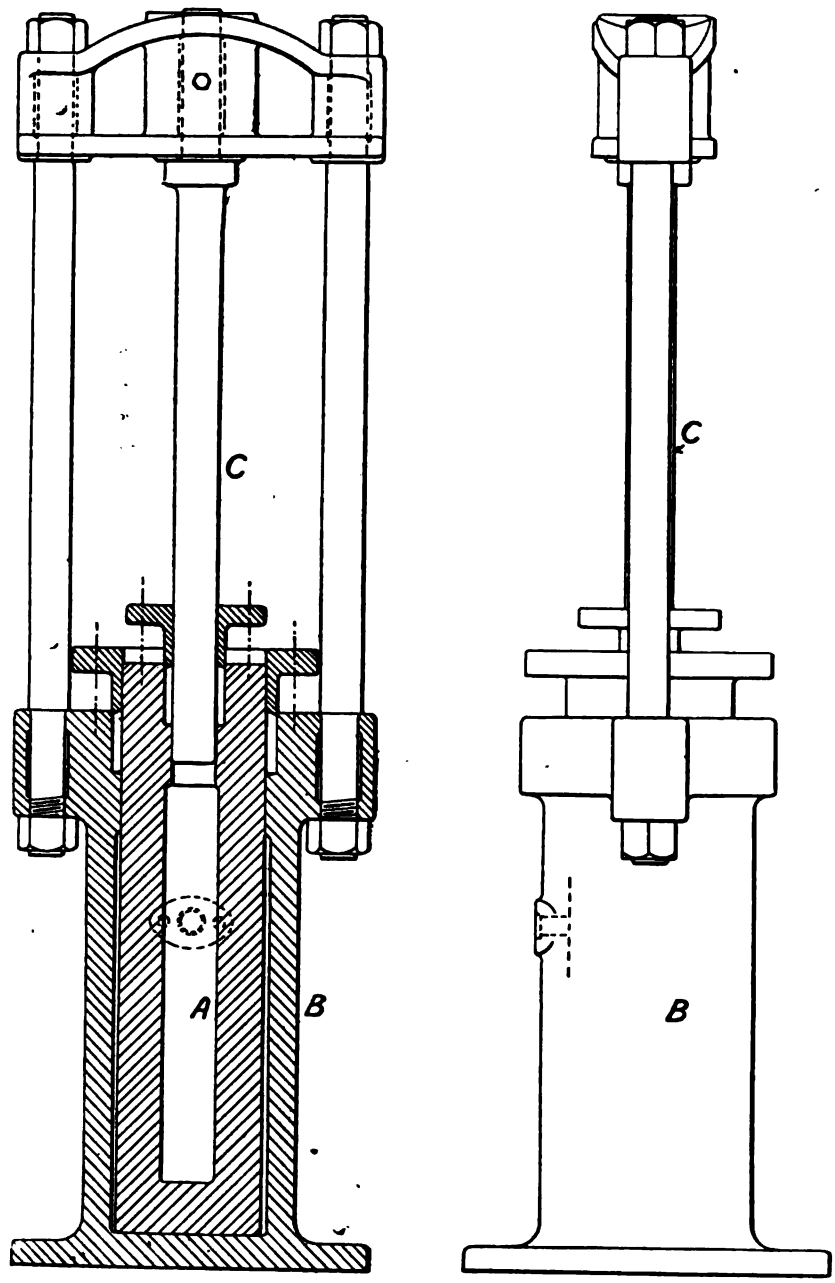

Fig. 4.—Intensifier, or Differential Accumulator.

and the capacity of cylinder in gallons. Rams vary in size from about 4 to 18 inches, and in stroke from about 6 to 20 feet.

A ring weight, or weight ring accumulator by the Hydraulic Engineering Co., Ltd., is shown in Fig. 3. It differs also from Fig. 1 in having no guides. It comprises as before the cylinder and ram, but the crosshead carries

two bolts, which support the loading weights on the bottom plate. The inlet and outlet pipes are screwed into the bottom plug.

Accumulators are fitted with a safety valve, and when belt-driven pumps are used, with a deflecting valve also, to allow the water delivered to be returned to the suction tank when the accumulator is at the top, so relieving the pumps of the load. If worked in conjunction with steam-driven pumps, an automatic hydraulic stopping and starting gear is often provided to act upon the steam valve.

At 1,500 lb. pressure per square inch, each gallon pumped into an accumulator is nearly the equivalent of one actual horse-power.

Fig. 4 illustrates an intensifier or differential accumulator in section, by Messrs Henry Berry & Co., Ltd. It comprises two cylinders of different diameters set axially. The ram A in the large cylinder B acts as a cylinder to the smaller and fixed ram C, which is held in position by a crosshead and tension bars. The pressure is brought on the large ram A in the bottom cylinder, the ram is pushed upwards, and the water displaced by the fixed ram C. Pressure is thus intensified on the smaller one inversely as the difference in their diameters. Thus if the larger ram is 8 inches diameter and the smaller one 3 inches, these areas will be as 50·265 is to 9·424. If the pressure on the large ram is 700 lb. per square inch, that on the small one will be—

9·424 : 50·265 :: 700 : 3733 lb. per sq. in.

Some intensifiers are made with removable weights for various pressures. Three-stage intensifiers are also made.

The casting of the cylinders and rams of accumulators has to be done on end if a sound job is to be made. The usual working pressure of 1,500 lb. per square inch soon finds out spongy portions of these castings, and it is hardly possible, except by chance, to get sound castings poured horizontally, the top metal being more porous than the bottom. And if risers are put on, the metal is spongy in their vicinity. Casting perpendicularly not only avoids this, but ensures denser metal throughout. In the writer's experience, heads of from 4 to 6 feet in length have been also cast, so ensuring that the metal up to the top of the actual casting shall be sound. This requires a deep casting pit, but it is essential. The pouring basin may, without inconvenience, be raised from 3 to 4 feet above the level of the foundry floor. Rams and cylinders are cast just as they stand when working, the stuffing-box end being uppermost. They are poured in dried sand.

A great difficulty in casting cylinders and rams is due to the cores. Chaplets are inadmissible, or at least very risky, because they produce some sponginess in their vicinity. The proper way is to sweep up the core on a very stiff bar, rigid enough to be self-supporting, and to carry it in a print impression of great length at the top end. Then, casting on end, the core is not likely to be washed out of centre to any appreciable amount. This applies only to cylinders and rams cast with blank ends. But when cylinders are cast with open ends, the lower one being bolted with an hydraulic joint to a base, prints can be fitted at both ends.

Rams must always be blank-ended. But a frequent practice is to core out the lower end simply to permit a print to be used there, to carry a thoroughfare core, making the hole less in diameter than that through the body of the ram, usually a 3-inch or 4-inch hole. Then it is bored and threaded, and a plug screwed in with rust cement.

In cases where a special order requires a cylinder and ram larger than the standard patterns furnish, expense can be saved by sweeping up a loam body to serve as a pattern, and making the flange for the stuffing box, and any other attachments in wood, and placing them in position on the loam body.

Acetylene Gas (sp. gr., 0·9).—Acetylene gas is remarkable alike for the simplicity of its generation, and for its high illuminating value. Although its production has long been a curiosity of chemistry, the commercial manufacture has been impossible, on the score of cost, until recent years. So long since as 1836 Professor Edmund Davy demonstrated the production of acetylene, although there was no prospect then of turning it to practical account. The cheap manufacture of calcium carbide (or carbide of calcium) has brought acetylene into extensive use. The carbide is produced by fusing coke

and lime together in the intense heat of the electric furnace, the result of which is a hard greyish substance, that gives off acetylene gas freely directly it is brought into contact with water. The chemical action which takes place is as follows:—

Calcium carbide is composed of the metal calcium and carbon—one part of the former to two of the latter—the symbol being CaC_2. Water is composed of two of hydrogen to one of oxygen—H_2O. When these are brought together the hydrogen of the water combining with the carbon of the carbide forms the hydrocarbon, acetylene—C_2H_2. The oxygen of the water simultaneously combines with the calcium of the carbide, producing lime (calcium oxide)—CaO. The latter, however, owing to the presence of the water or moisture, is actually immediately converted into slaked lime (calcium hydroxide)—$Ca(OH_2)$. The reactions put into the form of an equation therefore stand—

$$CaC_2 + 2H_2O = C_2H_2 + Ca(OH)_2.$$

During the evolution of the gas a certain amount of heat is developed. 1 lb. of carbide gives off an average of 5 cubic feet of gas.

The acetylene flame has a very high illuminating value, from 10 to 15 times that of coal-gas, besides which the light possesses great advantages from its near resemblance to the nature of sunlight, which renders it valuable for colour-matching, &c. A peculiarity of the light is its softness, very different from the dazzling glare of the naked electric arc. Comparatively little heat is produced by the combustion of acetylene, in comparison with the light yielded, and the exhaustion and pollution of the surrounding air is less than with any other form of illuminant, electricity excepted. The flame is remarkably steady. The danger arising from the use of acetylene is that due to its highly explosive character when mixed with air, a danger much more marked than with mixtures of coal-gas and air. A smaller percentage of acetylene than of coal-gas introduced into a volume of air is sufficient to form an explosive mixture, which is capable of being fired by a light, or an incandescent substance, as a cigar; even a spark will suffice (as with other explosives) to cause ignition. Thus it has been found that a percentage of 3·35 of acetylene in a body of air will produce an explosive mixture, while with coal-gas 7·9 per cent. of the latter is required before the dangerous point is reached. This means that greater precautions have to be taken in the handling of acetylene to prevent its escape into the air, or the accession of air to it while there is any chance of ignition being caused.

The unpleasant and unmistakable smell of acetylene gas, arising from impurities present in it, is a safeguard which leads to the detection of escapes. Some of the impurities are detrimental to proper burning, and the process of purification must therefore be performed. Remarks on these precautions will be offered later. Pure copper must not be employed in the construction of any apparatus used for acetylene service, because the gas acts upon the metal, and produces a highly explosive compound (an acetylide), which is liable to explode when heated, or subjected to friction.

With regard to the practical production of acetylene gas, it would seem that so apparently simple an operation as bringing water and calcium carbide together for the generation of the gas should involve no difficulties. Yet this matter has occupied the time of many experimentalists, and resulted in the evolution of numerous diverse types of generators. The first problem that arises is whether the water shall be conveyed to the carbide, or the carbide to the water. This is solved variously by pursuing both methods, with variations in the precise mode of working. A second important division of types of generators is that into "automatic," and "non-automatic"; in the first the gas is produced automatically, either continuously or intermittently, in such quantities as are demanded, while in the second a definite amount of gas is made from a certain quantity of carbide, and passed into a reservoir, from which it is drawn upon as required for consumption, the generator remaining inactive until another charge of carbide is put in and converted into gas. The automatic generator introduces more complication and chances of mishap, but this is really a question of good design, and careful workmanship in vital parts. The non-automatic type provides

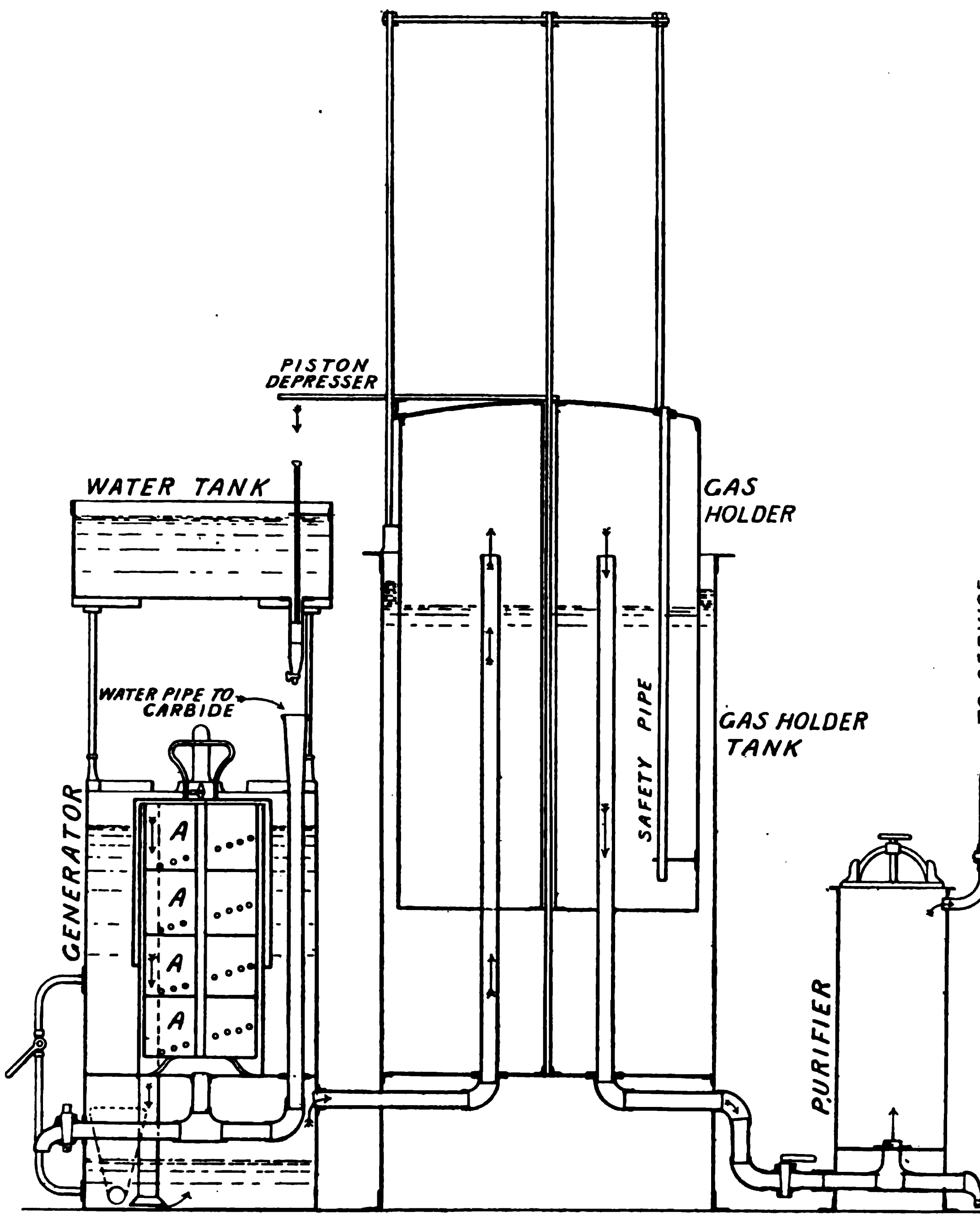

Fig. 5.—Automatic Water-to-Carbide Acetylene Generator, by the Acetylene Corporation of Great Britain, Ltd.

A, A. Carbide pans. Arrows indicate course of gas from pans, through the system.

a store of gas ready to be drawn upon as required to meet sudden and varying demands, but on the other hand the gasholder, of large size frequently, has to be provided, and space given to it, while it may not run for so long a time without attention as the automatic type. There is also a deterioration of the gas and an absorption by the water in the holder as a set-off to the advantages of storing.

With reference to the mode of bringing the two agents together; this leads to two alternative designs of generators, termed "water-to-carbide" and "carbide-to-water" types, both of which are in extensive use. The simplest mechanical method would appear to be that of pouring or dripping the water on to the carbide in such quantities as are required, but this is attended with certain disadvantages. The carbide being acted upon resolves itself into a compact mass, and as lime is produced, this coats the surfaces of the lumps of carbide, and interferes very soon with the proper action of the water, the result being that although the production of gas may cease, there will still be portions of unused carbide in the generator. The trouble and mess of removing these and separating the lime from the carbide, still capable of yielding gas, is sufficient reason for the condemnation of this manner of generating on anything like a reasonable scale. When the carbide is lumped together thus, great heat is also generated, which is very objectionable because of its effects upon the illuminating power of the acetylene; oily or tarry substances are produced by the excessive heating, which coat the carbide and interfere with its proper decomposition, as well as choking and making a mess in the working parts of the plant.

Applications where this manner of generating has been sufficiently successful, however, are those of cycle and motor car and similar portable lamps—generators on a small scale. It must be remembered, however, that but a small quantity of carbide is used for each charge, and the rapid passage of the vehicle through the air has a considerable cooling effect, which is not available nor adequate enough for large generators.

Another point is that in these dripping types, the supply of gas does not cease immediately the water supply is cut off, so disposing of one of the expected advantages of the easily controlled liquid. The amount of water intermingled with the carbide is sufficient to continue the yield of gas for some time after the water is shut off.

The objections arising from the presence of a mass of carbide (with its residue of lime) are, however, minimised by dividing up the charge into several portions, or cages, so that lumping is much lessened, and the undesirable heating and choking of action is considerably reduced.

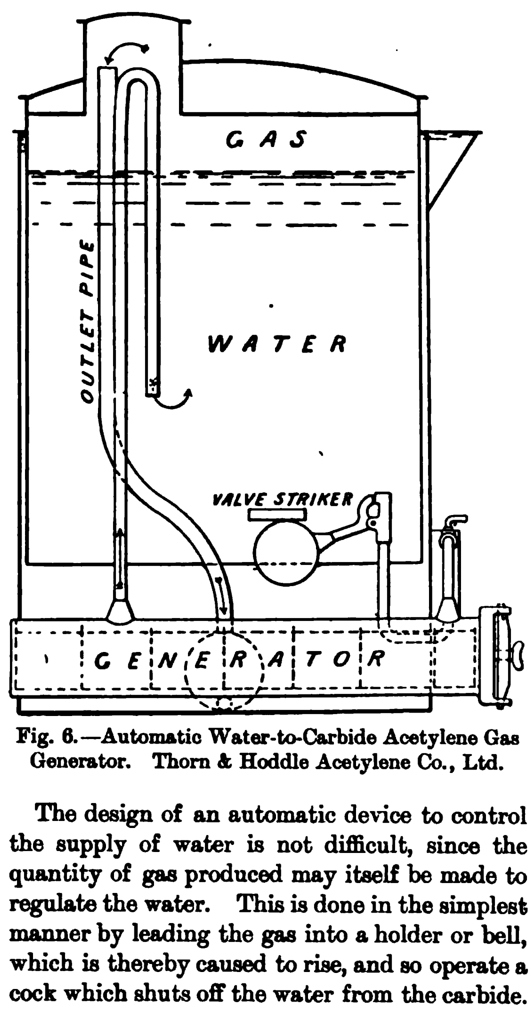

Fig. 6.—Automatic Water-to-Carbide Acetylene Gas Generator. Thorn & Hoddle Acetylene Co., Ltd.

The design of an automatic device to control the supply of water is not difficult, since the quantity of gas produced may itself be made to regulate the water. This is done in the simplest manner by leading the gas into a holder or bell, which is thereby caused to rise, and so operate a cock which shuts off the water from the carbide. As the gas is then used, the bell again sinks, and so opens the cock, allowing more water to decompose the carbide. It may be mentioned here that the same device is also applicable to those other generators in which either the

carbide is lowered into the water, or the latter is caused to rise up around the carbide, as in Fig. 5. In the first case the act of the bell lifting raises the carbide container out of the water, and *vice versa;* in the second the descent of the bell allows the water to rise up around the carbide, or checks it as the holder fills up. The bell itself may be a portion of the actual generator, as in Fig. 6, or as in the types where a separate gasholder is provided, Fig. 5, this will perform the automatic control of the generation.

The opposite condition of feeding—that of carbide to water—is done in the simplest manner by dropping lumps of carbide into a water container, the gas being generated very coolly and completely in this way. In the small hand-fed designs, carbide is thrown through a spout in the generator until enough gas has been evolved to fill the gasholder, which may be of sufficient capacity to give a supply for several hours' use. The simplicity of this mode of production is a feature which renders it of value for small installations. The method of feeding, however, becomes objectionable on a large scale, and some automatic device for supplying the carbide must be introduced. Many types of mechanism have been tried, some of which have proved erratic and unreliable, in a few cases being dangerous. Certain designs have, however, been sufficiently successful, an automatic ejector shooting the carbide into the water at intervals, as determined and controlled by the yield of gas. This method of letting carbide into a large excess of water has some advantages from the chemical standpoint. Heat is kept down, and the gas as it passes through the body of water is cooled and washed. The residue or sludge falls naturally to the bottom of the generator, whence it may be further led into a subsidiary receptacle for convenience of removal.

With an automatic feed to the carbide it is desirable that the latter should be in lumps of at least approximately even sizes in order to secure some degree of regularity in generation.

Another system is that of lowering a cage of carbide into water, and withdrawing it after a quantity of gas has been generated. This is not in very much favour, because it has the disadvantage that the mass of wet carbide being left isolated from the water gets heated unduly. In this respect the practice of dropping the carbide bodily into the water is a much better plan. The remaining method, that of causing the water to rise up in excess around the carbide, is in extensive use. The carbide, being contained in cages or perforated trays, is attacked from below, the water being admitted gradually by a cock, opened at intervals by the gasholder as it becomes depleted, and so descends. Each tray of carbide is thus successively attacked and decomposed, the action being divided up amongst several groups—a manifest advantage. Ease of cleaning out is also one of the recommendations of these tray containers, since the entire set can be lifted out bodily for the removal of the residue.

The acetylene gas produced by any of the various generators is never sufficiently pure to be utilised for illuminating, chiefly on account of the impurities present in the original carbide. The resulting gas may give trouble in several ways unless purified; injurious fumes may be evolved on combustion, and the pipes and burners will gradually get choked by deposits. One of the undesirable bodies present in acetylene is moisture or water vapour, which is not due to the carbide, but to the simple fact of the presence of water in the generator. This is mostly got rid of by first passing the gas through a condenser, having pipes immersed in cold water. This condenser, however, is often omitted, when a washer is employed to follow generation. The washer is intended specifically to remove such impurities from the gas as are soluble in water, but as the latter is cold it will also serve to cool down the gas and rid it of most of its moisture. Some of the impurities present in crude acetylene, as ammonia and sulphuretted hydrogen, are capable of removal by passing the gas through water. For such, however, as are not eliminated by the water, including phosphorus compounds, removal must be effected in another way, by the use of various substances. Bleaching powder or chloride of lime is in common use for this function, with additions which modify it somewhat. Chloride of calcium, chromic acid, and cuprous chloride are also employed, all of these being made up under various commercial names. One, "puratylene," besides chloride of lime, contains calcium chlo-

ride and calcium oxide (quicklime). Another, "heratol," is made up with chromic acid absorbed into a porous substance, "kieselguhr," for convenience of using in a lump state. It is acidified with hydrochloric or acetic acid, to enable it to deal with the ammonia of the gas. These and other agents are made up into porous masses, so that the gas is compelled to thoroughly permeate them, and thus be well purified. The substances are either spread out on trays in the purifier, or simply placed in the latter in a single compartment.

The action of these, besides abstracting the impurities which are undesirable, is also to lessen the unpleasant odour of crude acetylene, though this is not a feature of special value, because the strong smell of the gas is the surest method of detecting leakages. A purifier is most suitably of circular shape, the fittings comprising a removable gas-tight lid, and the inlet and outlet pipes for the gas.

Although some kinds of purifiers serve also to remove the final traces of moisture from the gas; if they do not act perfectly in this way, a separate drier may have to be employed, in which hygroscopic materials, as quicklime or calcium chloride, are used. Puratylene, which contains calcium chloride, will serve as a drier, either when used in the purifying vessel, or in a separate drying chamber.

From the drier,—the final portion of the generating plant,—the gas enters the service pipes. A meter (practically identical with that employed for measuring coal-gas) must be used to gauge the yield, unless the plant is very small, and it is not desired to know the exact production of gas at all times. A pressure governor is sometimes fitted, before the meter is reached, to ensure a steadiness of flow, in instances where there is a tendency to unevenness of pressure from the gasholder, or the purifier.

The location of the generating plant must be governed by circumstances, but it is best set away from the main building, when the gas is used for a dwelling-house. In the case of a public service, a special building will of course be provided. Certain precautions must be taken in running the plant because of the dangerous nature of the gas. A naked light must not be brought near the generator when it is in operation, or even for some time after it has ceased working, when no acetylene is presumably present. Explosions are easily caused by the presence (usually unsuspected) of traces of the gas. It follows, therefore, that the generator must not be charged or cleaned out at night, when the help of an artificial light is necessary; if the operation is done then, either an electric lamp must be used, or some form of lantern must be located outside the generating house, projecting its beams through a closed window. Precautions must be observed that no irresponsible person is allowed to meddle with the plant, or even go near it with cigar lit, nor may any form of flame be present.

Another matter which has to be considered in an acetylene installation is the risk of freezing in cold weather of the water contained in the various parts. Congelation of this would result in the stoppage of the production of gas. Suitable means for keeping the house up to a proper temperature, such as by hot-water pipes, must be adopted where necessary. One particular risk which presents itself is that of the water seal of the gasholder freezing, and so locking the rising portion. This must be prevented by an admixture of some substance which will lower the freezing point of the water, such as glycerine, alcohol, calcium chloride, salt, &c.

The materials of which the plant is constructed are in the case of generator and holders, steel, galvanised, to prevent corrosion, while for piping about the plant, good wrought-iron tube is best. It is not permissible, as previously mentioned, to employ copper, for pipes, &c., but alloys of it may be safely used, as brass and gunmetal, for the cocks and valves.

The piping for conveying the gas to the points of consumption is an important item, on which much care must be bestowed in order to ensure satisfactory and safe results. All joints must be exceptionally well made (even more so than those of coal-gas installations) to prevent losses, or dangerous leakages. Stout wrought-iron tubing is the most reliable form to employ. Composition tubing, as used for coal-gas, possesses the disadvantage of liability to damage from various causes. It may be mentioned that the sizes of piping for an acetylene installation may be smaller than those of a corresponding

plant for coal-gas of equivalent output of light, because of the far greater illuminating power of acetylene.

The cocks, swivel joints, &c., of the lighting fittings must be well made to prevent leakages. Special taps are provided for acetylene service, having larger bearing surfaces than those employed for coal-gas. If ball joints are used, as for suspension, a flexible pipe should be employed to connect the swivelling part of the pipe with the fixed one, so that escape of gas is doubly guarded against.

A necessary precaution in dealing with acetylene is that of thoroughly clearing the whole system of air before any burners are lit. As already mentioned, it is easy to get a dangerous mixture of the gas with air, and any attempt at lighting from an uncleared set of piping will result in an explosion, the worst feature of which is that it will not be confined only to the point at which the light is applied, but will extend through all the piping. It is therefore essential in starting up a plant to send enough acetylene through the pipes to clear out all the air, care being taken that the air and gas so sent out are not allowed to linger about in the rooms in which the burners will subsequently be lit. The clearing out must obviously be done in the daytime, with windows and doors open. The dissipation of the mixture is best facilitated by leading it from the house taps, &c., through rubber pipes into the outside air.

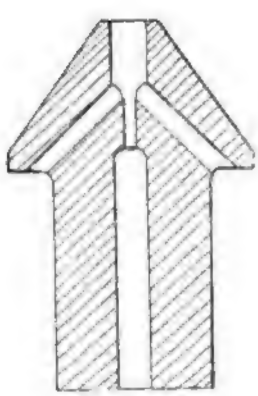

Fig. 7.—Section of Burner Tip, showing Central Gas, and Side Air Passages.

Acetylene gas is utilised either to produce a self-luminous flame, to heat a mantle to incandescence, as a Bunsen flame, or for driving gas engines. By far the most useful and extensive application is the first named, a field in which it cannot be approached by any commercial gas.

The difficulties which have been encountered in burning acetylene as a self-luminous flame are those due to "carbonisation," that is choking of the burner outlets with deposits from impurities present in the gas, which very easily collect and block up the minute apertures from which the gas issues. The manner in which this difficulty is mostly obviated is by forming the burner in such a way that the flame does not actually rest upon the burner, but occurs at some little distance from it. Instead of allowing the air necessary for combustion to meet the gas at the orifice where the lighting takes place, the Bunsen principle is adopted

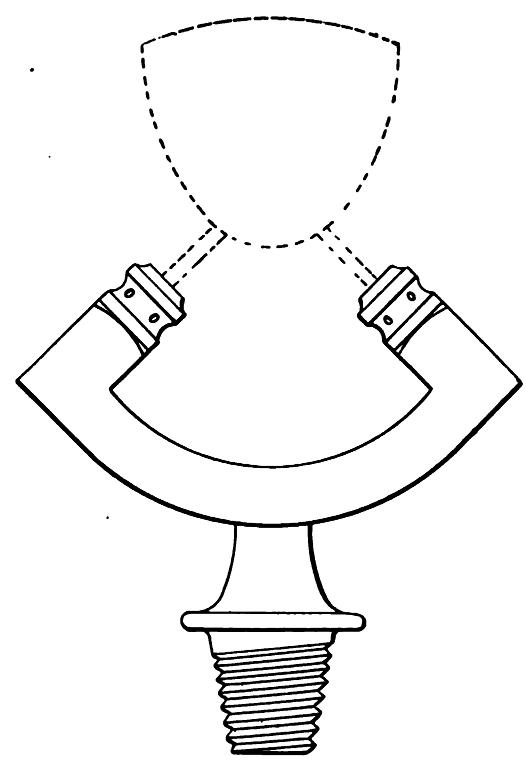

Fig. 8.—Double-armed Burner, having Jets impinging to form a Flat Flame.

(Fig. 7), holes being pierced laterally in the burner sides, so that as the gas rushes out through the central passage, it sucks in air from these side passages, which mixture mingles in the final portion of the opening, and burns with a flame which is carried out from the aperture some little way. As a single burner of this type gives a thin flame, or "rat-tail," it is not suitable for anything except a very small lamp or light; it is usual, therefore, to employ two

such burners, set pointing towards each other, so that the flames unite and form a flat flame, which gives light of reasonable intensity. There are many varieties of these burners, but the principle is illustrated in Fig. 8. Although carbonisation is practically avoided by these types of burners, they are still liable to the evil when the flame is turned low. Some designs have been evolved to get over this trouble, but the fact remains that a flame is best kept to its full efficiency when it is not habitually turned low by a by-pass, and the burner remains in perfect order for a longer period. Steatite is the material employed for the burner jets.

The employment of acetylene for heating up mantles of the "Welsbach" kind, although it may be successfully carried out, is hardly utilising the gas to its best advantage, that is by securing the pure white rays which are the most beautiful characteristics of the self-luminous flame. To employ the gas, therefore, for this purpose, is to lower it to the level of coal-gas, which is quite capable of illuminating mantles as well as the more costly acetylene. A fact which militates against the use of acetylene for incandescent lighting is that the phosphorus compounds which may frequently be present in gas which has not been perfectly purified have a deteriorating effect upon the substances used in the mantle, causing them to rapidly break up.

Acetylene is used to some extent for heating purposes in stoves, and heaters of various kinds, in a similar manner to coal-gas. Modifications in the capacities and forms of the inlet pipes have to be adopted, but successful results are achieved.

The subject of driving engines with acetylene gas will be better discussed under the head of **Gas Engine**, where it may be suitably compared with other forms of gas.

Acetylene may be "put up" into forms other than its natural state, as compressed, liquefied, and dissolved acetylene. Compression may be carried out, just as with other gases, until the acetylene is liquefied, but this operation is now forbidden by law in most countries, because of the extreme danger attendant upon the process. If compression alone is carried to more than one atmosphere, a danger is introduced, because of the liability of the gas to explode by ignition or shock, so that the much higher pressure involved when the gas is pressed to the point of liquefaction is out of the question for any practical uses. A very convenient method of storing acetylene, however, is by forcing it under pressure into that compound known as acetone, which dissolves the gas in quantity. In order to facilitate the absorption of the gas, and to enable portability of the container to be effected better, a solid porous material is employed, which carries the gas in its ramifications better than liquid acetone alone would do. In this manner the acetone may be made to absorb about 100 times its own bulk of acetylene gas under slight pressure. When the container is opened, through the medium of a suitable controlling valve, the acetylene in the form of dry gas escapes, and may be used for feeding lamps, &c. The advantage of this system lies chiefly in those cases where it is undesirable or inconvenient to instal or carry a generator for the gas, usually on a small scale, such as for motor vehicles, &c. A sufficient store of the gas may be had in a convenient cylinder to last for many hours, without the trouble and attendance required with a generator.

A useful combination of acetylene is that with oxygen, the two gases being used under slight pressure in a blowpipe, giving a heating effect more powerful than that of the oxy-hydrogen flame. The oxy-acetylene flame may be turned to similar uses, such as for heating up various substances, for welding, or for obtaining light for lantern work.

In general, we may say that acetylene gas does not enter into competition with coal-gas or electricity in cases where these are obtained easily, and cheaply. It is rather in isolated plants that acetylene scores, and in instances where a portable generator of light is required. Exceptions may, however, occur where acetylene will be deliberately installed, notwithstanding the fact that other agents may be easily had. This is the case where the specially actinic flame of acetylene is desirable, as for photographers, or where a powerful and concentrated source is wanted, as for lantern work, and special lamps of various kinds. For portable lights, as those of vehicles, acetylene offers

great advantages, because a volume of light may be obtained which could not be got by any other available means, as candles, oil, or electricity. This is seen in the various small lamps used for vehicles, &c., which while occupying but little more space than oil lamps, emit beams which are immensely superior to those of oil wicks.

Acetylene occupies a large field where isolated plants are wanted, in the absence of coal-gas or electricity. This is particularly the case in country mansions, which may well have an acetylene plant of their own. The attendance required on such a plant is less than that on a generating set for electricity, which is usually the alternative.

The industrial uses of acetylene are numerous, particularly for lighting in yards and factories, and on various works, where a supply of electricity is not available. The acetylene industry is already a very large one, and the many advantages of the gas are widely appreciated. A reduction in the expense of producing the carbide of calcium would have the result of still further extending the field of acetylene, but it must be remembered that the rather costly-run electric furnace is the only medium of production, and it is difficult to see how the expenses incidental to working this can be reduced to any great extent. Water-power is used for driving the generators for producing the current, which enables firms to make carbide at a cheaper rate than would be the case if steam were the source of power. Particulars of the manufacture of the carbide will be found under **Carbide of Calcium**.

Acid Cock.—A cock made of stoneware to withstand the action of strong acids used in chemical works. Such cocks are made with socketed, screwed, and plain ends, sometimes with flanged ends, and of straight-nosed and bib types, and as three-way cocks. They are obtainable in sizes ranging from $\frac{1}{4}$ inch to 2 inches.

Acid Process.—*See* **Bessemer Steel**, and **Open-Hearth Steel.**

Acid Pump.—A force pump made of stoneware, used for acids and alkalies, which would corrode iron or brass.

Acids.—The meaning formerly attached to the word acid was both wide and wonderful. Derived from Lat. *acidus*, sour, the term was applied to a number of solid, liquid, and gaseous compounds possessing a tart taste and the power of reddening vegetable blues. Then, after Lavoisier's discovery that certain substances burnt in oxygen produced bodies with acid properties, it was held that oxygen was an essential constituent of every acid. But it was pointed out that hydrochloric (HCL), hydriodic (HI), and hydrocyanic (HCN) acids were all free from oxygen, and yet possessed acid properties. Hence a subdivision arose—the oxi-acids, the more numerous class, containing oxygen; and the hydracids containing hydrogen. Then the theory was put forth that salts might be regarded as being formed by the displacement of one or more atoms of hydrogen by the metal presented in the form of a hydrate. Hydrogen, therefore, and not oxygen has now come to be regarded as the acidifying element, so that an acid may be correctly defined as a salt of hydrogen.

The number of atoms of hydrogen in an acid displaceable by an element, determines what is called its basicity. Nitric acid, (HNO_3), is monobasic because only one atom of hydrogen may be replaced by an element; sulphuric acid, (H_2SO_4), is dibasic since two atoms of hydrogen may be displaced; while phosphoric acid, (H_3PO_4), is tribasic, the three atoms of hydrogen being replaceable by three atoms of potassium or silver as in the following equation—

$$2H_3PO_4 + 3Ag_2O = 2(Ag_3PO_4) + 3H_2O$$

The following is a list of some of the chief acids:— Hydrochloric Acid, HCL; Hydrobromic Acid, HBr; Hydriodic Acid, HI; Hydrofluoric Acid, HF; Hydrocyanic Acid, HCN; Hydrogen Sulphide, H_2S; Sulphuric Acid, H_2SO_4; Nitric Acid, HNO_3; Carbonic Acid, H_2CO_3; Chloric Acid, $HCLO_3$; Perchloric Acid, $HCLO_4$; Iodic Acid, HIO_3; Periodic Acid, HIO_4; Sulphurous Acid, H_2SO_3; Hypophosphorous Acid, HPH_2O_2; Phosphoric Acid, H_3PO_4; Boric Acid, H_3BO_3; Phosphorous Acid, H_3PO_3.

Acid Steel.—*See* **Bessemer Steel**, and **Open-Hearth Steel.**

Acid Water.—The feed water of boilers which contains acids in solution corrodes the

plates and rivets, in the form of pitting, and honeycombing. *See* **Feed Waters, Boiler Corrosion, Boiler Explosions.**

Acme Screw Thread.—A screw thread of American origin which is used to a large extent as a feed screw. Its shape is a compromise between the Vee and the square thread. For description *see* **Screw Threads.**

Actinism.—Denotes the chemical action of sunlight on photographic films. *See* **Actinometer.**

Actinometer (Gr. *aktis*, genitive *aktinos* = a ray, and *metron* = a measure) is an instrument used in photography for measuring the intensity of light, and thereby estimating the correct exposure for the photographic plate. In the photographing of machinery this is of very great value, for the operator is called upon to photograph objects which may vary between a structure in the open, lighted by a flood of sunshine, and a machine in a dark corner of a badly lighted shop.

There are several types of actinometers, but they all consist essentially of a sensitive strip of paper which darkens on exposure to light, and the sensitiveness of which bears a known relation to that of the plate used. The exposure necessary will be in proportion to the length of time taken by the sensitive paper to darken to a standard tint. The earlier actinometers were regarded rather unfavourably, perhaps because the chloride paper was rather unreliable, but since Abney adopted bromide paper for actinometers they have come to be regarded as essential to those whose work is performed under widely varying conditions of light. Light, however, is only one of four factors which govern exposure—the speed of plate, diaphragm, and the subject all have to be considered, and the process is simplified in the majority of actinometers by a slide rule arrangement, one scale having to be set to another.

The verdict of the actinometer, however, can rarely be accepted as final, for the nature of the object to be photographed, and local conditions may demand a greater or less exposure than the instrument asks. A dark-coloured machine would certainly be under-exposed if actinometer time were strictly followed. Two, or even three, times the normal exposure would be necessary in such a case. On the other hand, a more distant light-coloured structure out of doors would need but three-quarters or half the normal exposure.

Action and Reaction.—It is one of the axioms of mechanics that the forces of action and reaction are equal and opposite in order to produce equilibrium. This fact has its application in every mechanical problem, and is the corner stone of the doctrine of the conservation of energy. The truth is expressed by Newton's third law of motion that "to every action there is always an equal and contrary reaction."

This fact is, however, disguised in various ways. It requires some little effort to believe that such a relation exists between the mass of the earth and a stone dropped upon it, but reasoning compels us to believe so. The relation between the flight of a rifle bullet and the recoil on the shoulder of the man who carries the rifle is more obvious, though the difference is still immense in apparent results. But the problem is rendered clearer if we remember that it is that of mass multiplied into velocity. The shock of two trains in collision is an evident illustration, but it is no more real than the shock between a stone and the earth, or that between an express train and a human being in its way. The difference is, that one is appreciable to the senses, and the other is not. The facts are further disguised in mechanical construction by the factor of safety in rigid parts, and the movement of portions of mechanisms in machinery. An abutment receives no more pressure than that due to its bridge, though it is made capable, by a large factor of safety, of withstanding five or six times that amount. The steam acts upon the cylinder cover with the same pressure that it exerts upon the moving piston, though the cover does not move. None of these things alter the axiom that a force always operates equally upon any two bodies between which it is exercised.

Action, Chemical, may occur in four chief ways:—(*a*) By double decomposition, an interchange of partners as it were. In the action represented by the equation

$$NaCL + AgNO_3 = AgCL + NaNO_3$$

we find the chlorine forsaking its partner sodium and uniting with silver, while NO_3 just as readily leaves its partner silver and hastens to unite with the sodium. (*b*) By displacement, as in the familiar experiment of dropping sodium on water, when hydrogen is displaced by the sodium. (*c*) By synthesis, as when iron filings and flowers of sulphur are heated together, forming ferrous sulphide. (*d*) By analysis, or decomposition by heating. Mercuric oxide heated in a test-tube darkens in colour; globules of mercury are formed on the sides of the tube, while a lighted splinter applied to the mouth reveals the presence of oxygen—

$$2HgO = 2Hg + O_2.$$

One of the most striking characteristics of chemical action is that the new compound formed is totally unlike the substances which produced it. Oxygen and hydrogen—two colourless, odourless gases—when chemically combined form water; black carbon and invisible hydrogen produce paraffin. Another characteristic of chemical action is the evolution of heat, apparent everywhere—in the burning of coal, the slaking of lime, the digestion of our food. Yet another peculiar characteristic is that the elements possessing the strongest tendency to combine with one another have opposite electrical properties.

Chemical action takes place only under certain conditions; some substances emphatically refuse to combine. Thus, no combination of fluorine with oxygen is known to exist. Chlorine and nitrogen too, reluctantly form a feeble combination easily broken up. Solids rarely react on one another, liquids do so readily, while gases combine with such eagerness as frequently to produce an explosion. Electricity assists in chemical action, as in electrolysis, or the decomposition of NH_3 into nitrogen and hydrogen. Heat also assists chemical action by lessening the force of cohesion between the molecules of a substance.

Chemical combination, whenever and however it takes place, always follows certain laws. The more important of these laws are given below.

1. *The Law of Constant Proportions.*—The same compound always consists of the same elements in the same proportions. Thus CO_2, whether it issues from our lungs or whether it be produced by the fire, always consists of carbon and oxygen in the proportion of 12 parts by weight of carbon and 31·9 parts by weight of oxygen.

2. *The Law of Multiple Proportions.*—When an element unites with another in different proportions, the higher proportions are simple multiples of the lower. For example, nitrous oxide consists of 28 parts of N to 15·96 of O; nitrogen trioxide, 28 parts N to 47·88 O; nitrogen pentoxide, 28 N to 79·80 oxygen. A glance at these figures shows that while the weight of N remains unchanged the weights of O are multiples of 15·96.

3. *Law of Reciprocal Proportion.*—If two bodies, A and B, combine with a third, C, they combine with each other only in proportions which are measures or multiples of the proportions in which they combine with the third body C. Example:—28 parts of nitrogen and 2 parts of hydrogen each combine with 16 parts of oxygen to form laughing gas and water. But ammonia is composed of 14 parts of nitrogen to 6 of hydrogen—which clearly illustrates this law.

4. *Guy Lussac's Law of Volumes.*—When gases unite to form compounds, their volumes bear a simple ratio to each other and to the volume of the resulting compound. Thus 2 volumes of hydrogen and 1 volume of oxygen form 2 volumes of water vapour; 1 volume of hydrogen and 1 volume of chlorine form 2 volumes of hydrochloric acid; 2 volumes of ammonia are formed from 3 volumes of hydrogen and 1 of nitrogen.

For the manner in which the Atomic Theory explains laws of chemical action and combination, *see* **Atom.**

Action, Mechanical.—This is distinguished from chemical action in the fact that it does not involve changes in chemical compounds, but changes due to the application of external forces on bodies.

Actual Horse Power.—The net power of an engine, left after the power absorbed by the engine itself is subtracted from the indicated horse power. Or the term is used to denote the indicated horse power.

Acute Angles.—*See* **Angle Iron.**

Adamson Flanged Seam.—*See* **Furnace Flues.**

Addendum.—That portion of the tooth of a gear which extends from the pitch line to the point of the tooth.

Additional Strength. — This term has many specific applications in different classes of work, but in its general sense it implies that structures subject to stresses above the normal must have additional strength imparted in those portions which are specially strained. In another sense it applies to sections which have broken down, or failed under test or in service. These are stiffened up and strengthened to prevent a recurrence of the failure. Errors and misconceptions in calculation are thus constantly being corrected by experience, and theory becomes subservient to practice.

Adhesion.—This denotes the weight necessary to prevent the slipping of wheels, on the exertion of tractive force upon them. It may be stated generally thus, but specifically it relates to the load on the wheels of locomotive engines. The tractive force of the engines being calculated, the adhesion must be equal to that. In other words, the load must be such that the driving wheels will not slip until a resistance is opposed to them at least equal to the tractive force. The amount of weight available for adhesion varies considerably, as is evidenced by the fact that an engine that does not slip in dry weather will do so in wet, and one that does not slip after speed is attained does so on starting. It explains also why some of the early locomotives were built for rack railways, but as the weight of engines increased, the racks were found to be unnecessary.

Under the most favourable circumstances one-fourth of the whole weight on the wheels is found to be available for adhesion. But one-sixth is usually considered more in harmony with average working conditions. In wet weather and on greasy rails adhesion is lessened considerably, going down to one-ninth. The total weight required, therefore, being so greatly in excess of the tractive force, cannot be sustained by a single pair of driving wheels without injury, the case of light engines excepted. But if the wheels are coupled, one pair cannot move without the others, and therefore the weight is divided between all the coupled wheels. *See* **Tractive Force.**

Adhesion also has reference to the cohesion of parts which are united with glues, cements, solders, &c. It is generally true that the strength of a good cementing material is, in a correctly made joint, equal to that of the materials joined. The essential conditions are that the cementing material must be of the best, and introduced under suitable conditions, and laid on thinly. Particulars of working these will be found under the heads of **Glue,** various **Cements,** and **Solders.**

Adiabatic Compression and Expansion.—*See* **Adiabatic Curve.**

Adiabatic Curve (Gr. *adiabatos,* not to be crossed, or passed).—If a pure gas is subjected to compression and is receiving, or losing heat sufficient to keep its temperature constant, its behaviour is different from that which results from compression produced in a vessel from which heat is not allowed to escape, or into which heat cannot enter. An indicator diagram taken under the first conditions produces an isothermal curve. One taken under the second produces an adiabatic curve, this term being due to Professor Rankine.

A greater increase in pressure is required when a substance is prevented from gaining or losing heat than when it is kept at a constant temperature.

The distinction may be put more clearly, by supposing in the case of adiabatics, that the gas is confined in a vessel which is a perfect non-conductor of heat, so that heat cannot by any possibility escape from, or enter the vessel—an imaginary supposition. In the case of isothermals, constant temperature is supposed to be maintained by using a vessel which is a perfect conductor of heat, and surrounding it with a body of fluid so large that the heat it receives from the vessel resulting from the compression of the gas does not alter its temperature sensibly.

As a greater increase of pressure is required when a substance is prevented from gaining or losing heat than under the other condition, so too the volume resulting from a given pressure is greater; or in other words its diminution is less when the heat is thus confined.

The relations of the isothermals and adiabatics afford a means of understanding the problems of thermodynamics, which have their applications in all kinds of heat engines, air compressors, and refrigerating and condensing apparatus.

Adit (Lat. *aditus*, entrance or avenue).—The entrance to a mine.

Adjustable, Adjustment.—The terms adjustable and adjustment are in common use in relation to mechanisms, but they do not always signify the same thing. Thus, adjustments may be made in cases where it would not be correct to term the parts adjustable. For instance, we do not speak of an adjustable lathe, or engine, though both of them require to be levelled and corrected in various ways before being set to work. And on the other hand certain parts that are termed adjustable receive no corrections until after they have become sensibly worn. So that a mechanism is adjustable when it contains provision for taking up wear, or for correct setting required for any reason, but adjustment is done both for purposes of erection, and for correction due to wear and tear.

The ever-growing importance of making these various corrections is due to the greater demands that are made on accuracy and precision in mechanisms. In it are included foundations, and the stability of walls, shafts, and bearings, machine spindles, slides and screws, toothed gears and much else. The minuteness of adjustment required in some cases can only be obtained by screws of fine pitch, and in these is often included the micrometric measurement to $\frac{1}{1000}$ part of an inch or less. What this involves in fine workmanship can only be understood by a study of the details of the high-class machine tools and instruments in which they are embodied.

There are two main ideas in providing adjustable portions, being either for convenience of manufacture, or for future adjustments. For much fine machinery, and also for massive kinds, it is impossible to finish certain parts true in solid portions when they are dependent for their action upon other portions. In the simplest of such instances, the screws or bolts which attach these parts to their frames are fitted so as to allow of variable positions being assumed, as are found necessary when erecting the mechanism. A large amount of trial and testing may have to be done before perfection of action is secured, and the various parts will be shifted, perhaps to minute amounts, until their final location has been determined. This form of adjustment constitutes the fitter's or erector's work, and is performed after all the other stages of work have been carried through, at the assembling of a complete mechanism. It calls for a good deal of skill and judgment, but its amount varies with the quality of workmanship and the class of machine which is under construction. The adjustments, for example, necessary in fitting up a common winch or a cheap steam engine are almost *nil* compared with those of a high-class engine or a fine machine tool. The adjustments of bearings, and of valve, and other gears in the engine, occupy a large amount of time, while in the machine tool, still more careful settings have to be done, because the machine is to be used for producing work which shall be as accurate as possible, within certain limits. On a machine tool, therefore, after all the surfaces and bearings have been fitted, there still remains the final adjustment of the parts in correct relations to each other, the principal factor of which is getting **Alignments** accurately. Without such setting, no matter how well fitted the parts may be, the work produced by the machine cannot be true. Thus, the mandrel of a lathe head may be fitted ever so excellently, but that will not avail it should the entire head not be in alignment with the lathe bed, and true work will not be possible. A considerable amount of delicate testing and setting has therefore to be performed on such machinery, and various methods are employed for ascertaining the presence and amount of inaccuracies. The indicator plays an important part in this work, because it enables one to detect minute amounts of error without difficulty.

The other aspect of adjustment, that of consideration of future necessities, is introduced by the fact of wear occurring and inducing slackness. To overcome this, various vital portions are so constructed that they can be closed inwards, or together, in small amounts as required, so as to retain a constant close fit between working

portions. There are many methods of effecting these adjustments, and they will be found discussed under different headings, including **Adjusting Screws, Adjusting Strips, Bearings,** &c.

Adjustable Caliper Gauge.—*See* **Caliper Gauge.**

Adjustable Reamers.—*See* **Reamers.**

Adjustable Taps.—*See* **Taps.**

Adjusting Bearings.—*See* **Bearings.**

Adjusting Cones.—*See* **Cone Bearings.**

Adjusting Screws.—The employment of screws for the purpose of effecting adjustments, as distinct from fastenings, is one of their most prominent functions, and one which they are better fitted to perform than any other devices. The power of being able to produce exact and minute movements is a most valuable one in many classes of machinery, more particularly in some, such as machine tools. Various portions have to be moved to certain distances, either quickly, or more usually slowly, as in setting and feeding cutting tools. These distances are either gauged by trial, or test, or a predetermined and definite amount of travel is given. The latter feature is one of the most useful results which may be obtained by using screws. The method of determining the movement which a screw will have, or will impart to its nut, is simple. It consists in dividing round the periphery of the screw, or more conveniently, a disc or wheel placed upon it, into a certain number of parts, bearing some relation to the pitch of the screw. Thus if the latter is 1 inch it will travel its nut exactly 1 inch if given a single revolution. Half a turn will move the nut $\frac{1}{2}$ inch, quarter turn $\frac{1}{4}$ inch, and so on. So that by dividing round the boss into a number of parts, the screw may be given a definite portion of a revolution, as indicated by the graduations. If the latter numbered 50 parts, the movement from one division to the next would turn the screw $\frac{1}{50}$, and consequently move the nut $\frac{1}{50}$ along. If divided into $\frac{1}{100}$, then $\frac{1}{100}$ of travel would result. In practice, on good machines, it is usual to provide for travel by thousandths, the screws being of a finer pitch than the 1 inch instanced for purposes of illustration. Thus a screw of $\frac{1}{10}$ inch pitch may be employed, and with a disc divided into 100 parts, thousandths of travel are effected. This can be halved with care by moving only half a division. A typical example of a micrometric fitting for moving a machine tool slide is shown in Fig. 9.

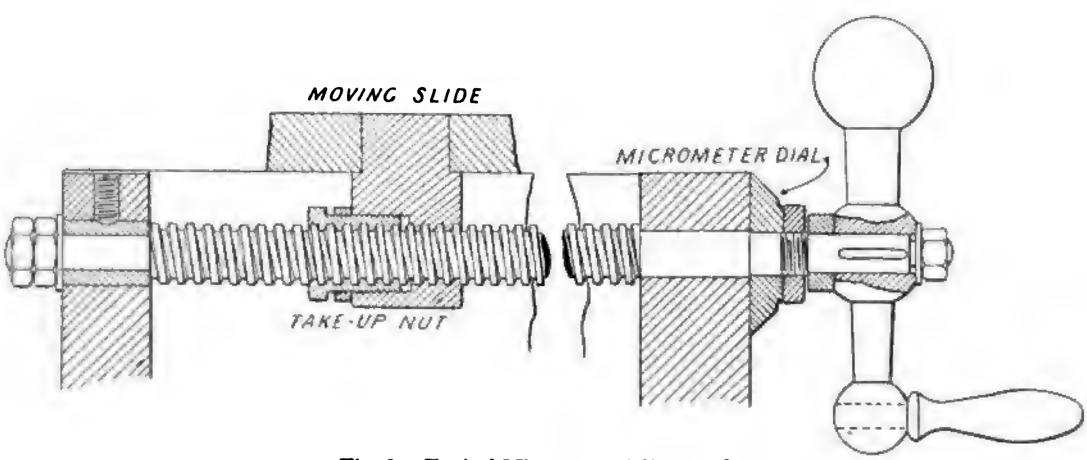

Fig. 9.—Typical Micrometer Adjusting Screw.

It is desirable to have the divided disc of large size in order to be more free from any errors in dividing, which are likely to creep in on small diameters, and to avoid crowding of the graduations on a small boss. In many cases a special disc is attached to the screw, next to the operating handle, or the latter is replaced with a hand wheel, and the divisions are placed upon the flattened periphery of this. A necessary precaution when reversing the motion of such a screw is to take up the slack

(which is bound to exist, due to wear), by turning until the loose feeling gives place to the "working touch," and then commence to read off the graduations.

These micrometric screws are fitted to nearly all classes of machine tools, and to various fine instruments, and they effect what could not be done with precision in any other way. They constitute what we may term the most refined class of adjusting screws. An alternative method of arriving at definite amounts of travel on a slide is to place graduations on it, so that as these pass a fixed point the distance travelled can be read off. This, however, does not bring the screw into use as a measuring agent, but simply allows it to perform its common function as a moving device.

For certain purposes, very quick pitched, or double or treble threaded screws are employed for adjustment where portions have to be travelled very rapidly, and in a short space of time. Quick withdrawal and quick return motions for various purposes are sometimes operated by such screws.

Though the majority of these adjusting screws are revolved by hand, either with handles or hand wheels, many are operated by power through gear wheels, in cases where the mass of slides, &c., is too great for human power to move with any reasonable despatch.

To enable adjusting screws to be moved with ease, many in the best machines are provided with ball-thrust collars, which reduce the friction due to end thrust considerably. This is done with a view not so much to ease the operator's work, as to enable delicate movements to be given. A heavy thrust on a plain shoulder means considerable effort in turning, and this results in a stiff and somewhat clumsy motion which is not conducive to fine and accurate settings.

When an adjusting screw is used to impart motion to a nut, the screw must be prevented from end-long movement. This is done by providing a collar at one end, and a nut and washer at the other. Or frequently the motion, both back and forth, is controlled at one end by retaining the collar between two faces, such as those of a slide, and of a separate bridging plate.

The operating handles cannot always be fixed directly upon the screws, but a change of direction of movement may be essential. In such cases a separate shaft may convey motion to the screw through the medium of bevel or other gears. Sometimes it is necessary that two or more adjusting screws shall be operated in unison; this is seen for example in the vertical screws in the housings of metal planing machines, which have to raise and lower the cross-rail. The two screws are therefore connected and revolved simultaneously from a single horizontal shaft, through bevel or other gears.

In a few cases the adjusting screws do not revolve, but their nuts, carrying with them portions, such as slides, turn on them, a practice adopted in very massive screws.

Another large and common family of adjusting screws are those employed for setting parts of mechanism, quite apart from the frequently moved slides of many machines. This setting is done either to take up slackness induced by wear, or to change the position of parts to accommodate varying dimensions, or differences produced by new and altered conditions. The most common and typical example of this is shown in Fig. 10, in which an ordinary set screw goes in a boss, and its point presses against a face which has to be adjusted; a lock nut is sometimes provided to prevent the screw from slacking back. This is representative of an immense number of applications, such as for moving dynamos and motors on their base-plates, to accommodate various belt lengths, shifting bearings of all kinds, adjusting machine tool portions, &c. The screw does not serve for holding down the parts when adjusted, because the clamping screws, or bolts (see the figure), do that, but it moves by minute amounts, and when locked, prevents the portion

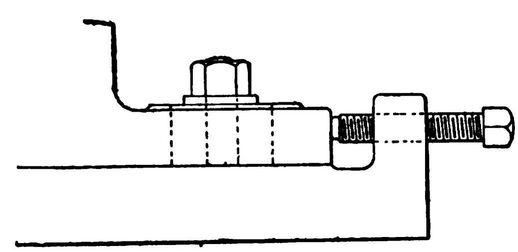

Fig. 10.—Adjusting Screw for Sliding Base.

from slipping backwards again. When frequent adjustments are necessary, a hand wheel takes the place of the squared head shown in the figure. The only alternative to a screw would be a wedge, which is a more clumsy and uncertain device. In fine mechanisms, small slotted head, or headless grub screws take the place of the headed set screw. Instead of employing a lock nut, sometimes the boss in which the screw runs is split and closed in with another screw lying transversely to the one used as an adjuster. This has some advantages when very fine amounts of travel have to be imparted, as it is rather more convenient to loosen and to lock the adjusting screw by the split boss than to slacken and tighten a lock nut. The split boss also closes all around the screw and grips it very firmly.

Screws of this kind are also considerably used for forcing in wedge pieces, and for pressing against adjusting strips. There is no possibility of their "giving" or moving, because the pressure comes in line with the longitudinal axis of the screws. Another function of such screws is that of arresting the motion of slides at certain definite positions, in the case of machines where an exact amount of travel has to be repeated a large number of times. They are then termed stop screws, though their power of adjustability brings them under the category of this article.

Adjusting screws of the type under discussion do not always act by pressing with their ends; it is often more convenient to push with the head for some small kinds of mechanism. This is the case frequently in adjusting small tools in holders, such as those called box tools, used in turret lathes. We need not illustrate an example of this form of adjustment, because instances will be seen in the drawings of box tools to be shown under that heading. Yet another application, also applied much to box tools, for setting the little cutters, is that where the head of the screw serves a double function, that of moving both forwards and backwards. To effect this useful movement, a notch is cut in the tool or other piece to be adjusted, and the screw head fitting in this, compels the piece to travel with it in either direction. This motion is extremely useful for setting to minute amounts, by trial and error, since a part of a turn of the screw serves to move the piece forward, or draw it back as required, until the exact position necessary is found. The screw head also plays an important part in retaining the set piece from subsequently shifting, with the help of the usual clamping screw, or screws.

Other applications of adjusting screws are those where another portion takes the duty of adjustment actually, while the screws serve the purpose of pushing. Thus split rings and collars are closed in by means of screws, though the latter do not touch the work so adjusted. Screws in the form of ring nuts also constitute an important section of adjusting screws. These will be found under **Bearings**.

Various adjusting screws will be seen on the drawings of machines scattered through this work, and we need not therefore illustrate a large number in detail in the present article.

Adjusting Strips.—These are also termed setting-up strips, take-up strips, and gibs. They constitute the means by which a constant working fit, without slackness, is maintained in sliding portions of mechanism, other than those of circular shape. They occur in practically all machinery possessing reciprocating or traversing parts, but their most frequent employment is in engine slides, and in the slides of machine tools, which are particularly rich in them. The necessity for adjusting a slide so that it shall move without slack or lateral shake is apparent both when fitting up the mechanism, and subsequently, when wear has produced looseness. It is especially important in the case of machine tools, where the slightest amount of slackness will result in bad work being produced. A slide or carriage travelling on a bed cannot operate with precision if it is able to wander about slightly. Cutting in such a case is rendered inaccurate and difficult.

Adjusting strips of the simplest form are those which are adjusted only by the removal of metal, either from the solid, or in the form of thin pieces. A strip may thus be closed in upon the face which it controls by filing away a little of the metal on which the strip is fastened. This is satisfactory in some cases, as in engine crosshead guides, and the adjustment being needed but infrequently, the method of setting

is not objectionable. In certain cases, thickness or packing strips are purposely inserted between faces in the beginning, and letting-down is performed by reducing these strips in number, or by substituting other and thinner ones. This method has much to commend it, and is extensively used for adjusting bearings of various kinds. The solidity and unyielding nature of

This method can, however, only be applied when there are two separate portions capable of being closed towards each other for taking up slackness. In the majority of machine slides there is no such capability, but one rigid slide has to embrace its guiding one, and the case is just reversed. Instead of reducing the thickness of the adjusting strip it must be increased,

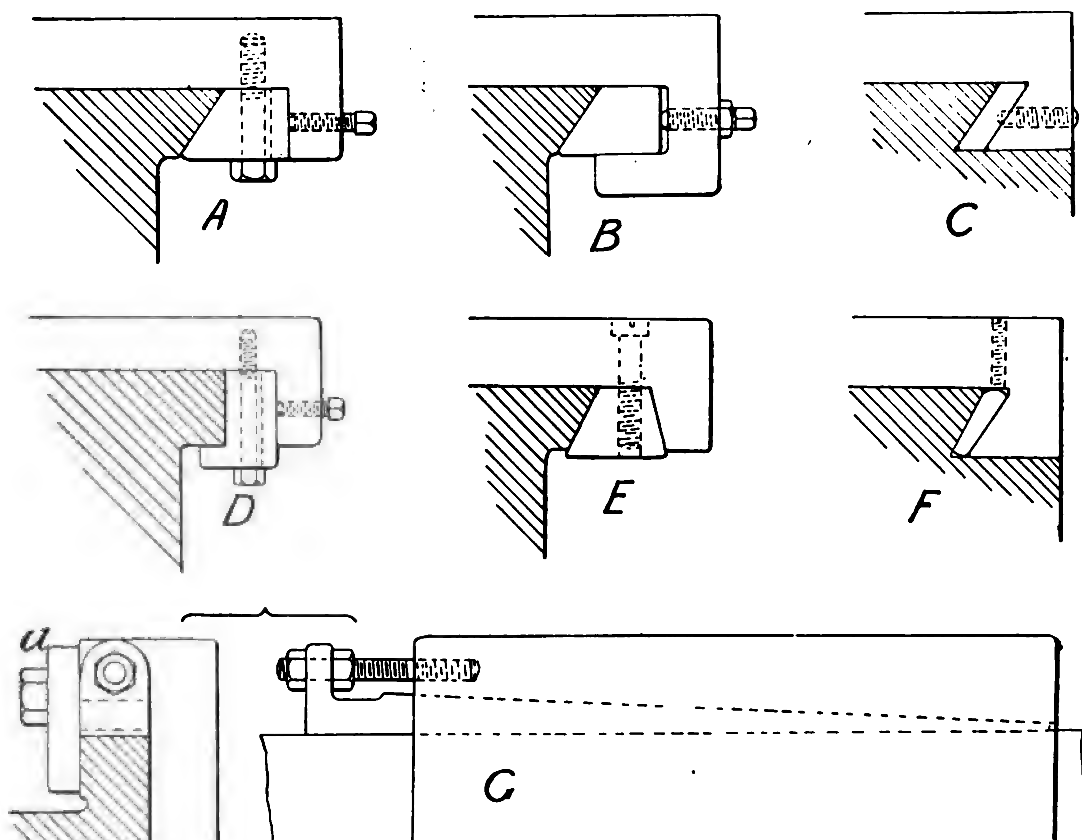

Fig. 11.—*A*. Common Vee strip, with clamping and setting-up screws. *B*. Vee strip supported by ledge of slide. *C*. Thin strip supported by ledge. *D*. Square-edged strip. *E*. Wedge strip pulled up by screws. *F*. Thin wedge strip pushed down by screws. *G*. Longitudinal wedge strip, adjusted by nuts on stud. *a*. Plate to prevent lifting of slide.

the strips renders their use desirable where setting by means of screws would be more complicated and not so reliable. Frequently there is no space to get screws in, even if they were considered at all. A small amount of material removed from the strips by grinding, filing, or more delicately by scraping suffices to effect minute differences in fit.

to fill up the space which is allowing slack working to occur. As it is usually unpractical and undesirable to insert a new and thicker strip, the alternative of an adjustable one is employed. These assume two main forms, those adjusted in a direct line by screws, and those which are tapered and act as wedges, when drawn or pushed in. The latter are the most

rigid and unyielding; but the former, when properly applied, are very satisfactory.

The most common form of adjusting strip, and one which has been employed more extensively than any other, is shown in Fig. 11, A. In this, one set of screws serves to press the strip against the Vee'd slide, while another set draws it up against the holding slide. This is a very efficient type, used on both the lightest and the heaviest machines. A somewhat similar form is that shown at B, where the top slide is carried down and under, to support the strip against lifting. The vertical clamping screws are often done away with in this design, because the projecting lip sufficiently supports the strip.

Another pattern which finds considerable favour in machines of light and medium sizes is that in C. A thin strip is set up to the slide by screws, which take the pressure. Although the method of receiving the thrust on the screw ends does not seem a very good one, the device nevertheless answers very well, and has the merit of simplicity. In strips of this type, having side-setting screws, the number of the latter may range from two up to a dozen or more, dependent entirely upon the length of the slide. There must be no chance for the strip to sag between any two screws, and so avoid its proper duty of keeping up to the slide.

The Vee'd form is imparted to the edges of slides in order to prevent lifting, and only one strip is necessary in such a form. But if square-edged slides are used, as is very often the case, a single plain strip is not enough, because both lateral and vertical movements have to be prevented. The type then used is that at D, an additional bottom strip being fitted to stop the slide from rising up when in service. As wear occurs, the slack is taken up by removing material from the strip, or from the under edge of the slide, to enable the strip to close up. The side-setting strip is unaffected by this adjustment, and is moved by its screws. To avoid the extra complication of the two pieces, a single angle strip is often employed, fitting around the corner, and somewhat simplifying the work.

Designs in which the pressure is not taken directly by the setting screws are in much favour, and will probably survive the other kind, especially as one considers how the strains on modern machines are increased by the greater duties demanded of them than was formerly the case. In this respect the solid strips mentioned previously are the most reliable, and if some means of easy adjustment is provided nothing better can be wished. A wedge shape imparted to a solid strip fulfils this desired adjustability. Three different styles of wedge strips are here shown. The first, E, has its sides bevelled, to bear against the fixed and the moving slides. It will be seen that the pressure due to the working of the slide, goes from one bevelled face to the other, and is taken by solid metal, not upon the points of screws. The latter, standing vertically, serve to draw up the strip to its fit.

The recommendation of solidity applies also to the next illustration, F, which is used to a very great extent, especially on the lighter classes of machine tools. It is the same in principle as E, but rather simplified from the practical point of view, because it is only a thin strip, and does not involve the extra work of drilling holes in it for the tightening screws. This fact renders removal and replacement also much easier, since there is no time consumed in taking out and reinserting screws. If the latter are slackened back a little way, the wedge can be pushed back, and then slid out endwise. This cannot be done with the type in E, which necessitates the removal of the screws altogether before the strip can be detached.

A yet simpler plan of fitting is that in G, in which the necessity for having a row of adjusting screws in the slide is obviated, by pushing the long wedge piece endwise with a single screw. The latter is tapped into the moving slide, and a couple of nuts embracing either side of an outstanding lug on the adjusting strip enable the latter to be moved and locked firmly where required. This mode of setting is quicker and simpler than having to attend to a row of six or eight or more side-setting screws. In very long slides instead of having the one wedge piece, two of them may be employed, pushed in from either end. An alternative method by which the wedge may be adjusted is by a screw lying alongside, the head pressing upon the end of the strip. This particular device is used in a

good many ways for moving adjusting strips of various types.

Another method sometimes used, for increasing the width of strips, is to split the latter, and force them open with a tapered screw, or by a screw having a tapered portion on its body or head.

The materials from which adjusting strips are made must be durable, to avoid too rapid wear. Cast iron is very much used, and gun-metal also, for the smaller strips. The fitting is done in the same manner as the other parts of the machine slides. In the best work the strips must be scraped to a fit, to get good contact all along, and so prevent the rapid working loose of the slide, which would ensue if the strip only touched in a few spots.

Adjustment.—*See* **Adjustable**.

Adjutage.—An adjutage is a mouthpiece or nozzle of a particular longitudinal section, designed to lessen the loss of volume of an issuing fluid, due to the contraction of the area of the jet.

The least efficient opening is an orifice in a thin plate, Fig. 12, A, with sharp edges. If such an opening is circular, the diameter of the issuing jet will be 0·784 to 0·8 that of the orifice, and its area will be only about 0·64 that of the area of the orifice. The value of the coefficient will vary from 0·61 to 0·64, according to the experiments of different observers. The greatest contraction will occur at a distance from the plate equal to half the diameter of the orifice.

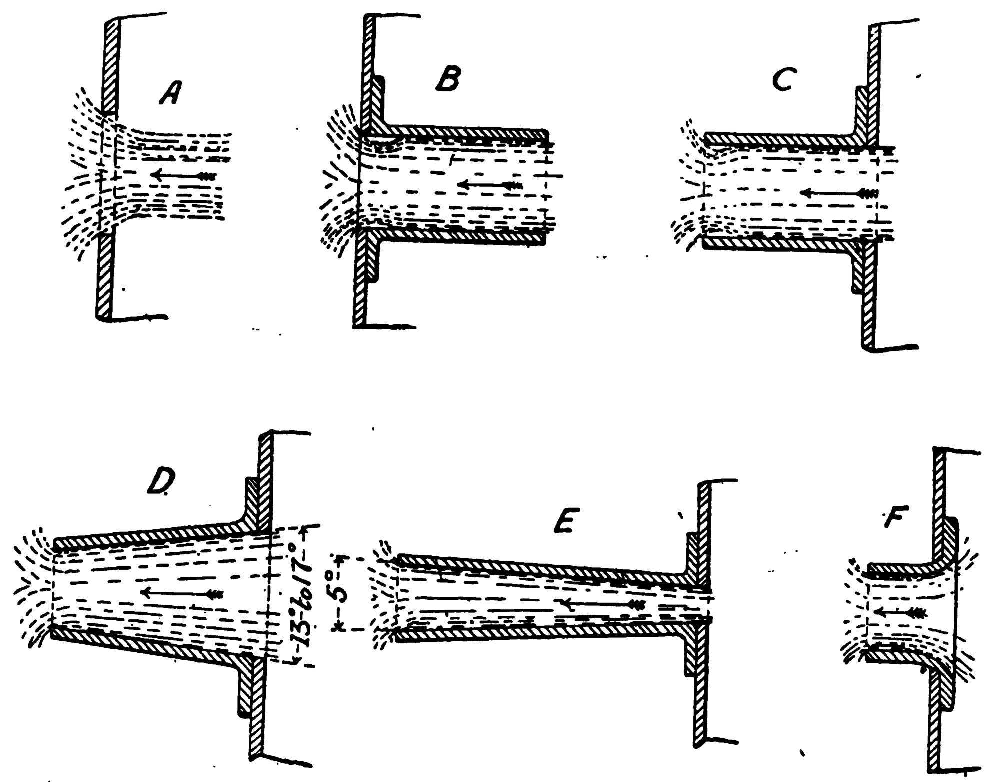

Fig. 12.—Forms of Adjutages, or Mouthpieces.

In practice such openings are not employed, except for gauging the flow of water, for which they are most valuable, but instead, adjutages of different sectional forms are fitted to orifices for the discharge of liquids. As every form has a different economical value, or coefficient, it is possible to select nozzles which can be best adapted to the class of work being

installed. Practically they include parallel mouthpieces, placed either within or without the tank or reservoir, mouthpieces that converge, or that diverge, and compound mouthpieces which are convergent for a portion of their length, and divergent for the remainder.

If a *short* parallel tube is attached within a tank, that is as bad a form as a simple opening in a thin plate, giving only about 0·52, and it is therefore not to be considered. But if the parallel tube has a length of twice the bore, Fig. 12, B, the coefficient is increased, for the diameter of the jet at the contracted part becomes 0·9 and its area 0·8 that of the orifice. If the tube is attached outside, as at C, the efficiency is also increased, and its amount depends on the particular relation which exists between the diameter and length. The best results are obtained when the bore is equal to from one-half to one-third of the length, giving a coefficient of 0·81 to 0·82. With further increase in length the value gradually diminishes.

Between the short tube and the thin plate there is the case of a thick plate, which, as might be expected, gives a result midway between the two, since its thickness obviously approximates to the length of the tube.

The highest results are obtained from a converging mouthpiece, which explains why this form is adopted generally for the outlets of tanks. If the angle included between the sides ranges from 13 degrees to 17 degrees, Fig. 12, D, a coefficient of from 0·94 to 0·99 is obtained. A diverging mouthpiece gives similar results, that shown at E, from Venturi's experiments, giving a divergence of 5 deg. 6 min. on a length nine times the diameter, as the best. Converging and diverging shapes are combined in one mouthpiece with results equal to those of single cones.

The conoidal orifice, Fig. 12, F, has a section similar to that of a vein contracted through a thin plate, giving a coefficient of from about 0·95 to 0·99, according to the head. The result is therefore similar to that produced by the converging mouthpiece. This "bellmouthing" as it is termed, is the practical device which is seen in numerous details of tank and hydraulic fittings.

Admiralty Bronze.—A mixture adopted for general bronze castings and propellers. Its composition is 87 per cent. of copper, 8 per cent. of tin, and 5 per cent. of zinc. Its tensile strength is about 15 tons, but the average strength of its castings is taken at about 13½ tons.

Admiralty Horse Power.—An obsolete formula, once adopted by the Admiralty for rating marine engines. It was

$$\text{Admiralty Nominal HP.}\left\{\frac{\text{area of piston} \times \text{speed of piston} \times 7}{33{,}000}\right.$$

Afterwards it came to mean one-sixth of the IHP.

Admiralty Knot.—1·15152 statute miles, or 6,080 feet, or 1853·169 metres.

Admiralty Tests.—These relate to tests made on boiler plates, angles, and other sections. *See* **Boilers, Materials for; Forge Tests; Tests—Official.**

Admission.—Denotes either the instant of the entrance of steam to an engine cylinder, or the entire period during which it is admitted until the moment of cut off, when expansion begins.

Admission Corner.—The corner of an indicator diagram which shows the method of the entry of the steam into an engine cylinder. *See* **Indicator Diagram.**

Admission Line.—The line or curve which denotes the rise of pressure produced by the steam during its admission into an engine cylinder. *See* **Indicator Diagram.**

Admission Port.—The port through which steam is admitted into an engine cylinder. Steam is admitted to, and exhausts from each port alternately in an ordinary slide valve engine. In a Corliss engine the two functions are confined to distinct ports.

Adulteration of Oils.—*See* **Oils.**

Advance. — *See* **Slide Valves, Valve Gears.**

Advance,—Angles of.—*See* **Slide Valves, Valve Gears.**

Adze.—A cutting tool, Fig. 13, most nearly related to the axe, from which it differs in having its cutting edge at right angles with the plane of the handle instead of in the same plane, and also in the fact that it acts more frequently by cutting than as a splitting wedge, which is

the most common way in which the axe operates. There is a difference also in the method of grinding, the adze having its bevel on one face only,—the inner one, while the axe is doubly bevelled. The plain face of the adze is not a true plane, but is curved approximately to the radius which the tool makes when being swung by its handle. Hence the surface cut by the tool is composed of a number of minute concave facets.

The great value of the adze lies in its capabilities for roughing down heavy timber rapidly, operating both as a splitting and a finishing tool. Its value is greatest in roughing pieces of irregular outlines, or very heavy masses which either cannot be reduced with a circular saw, or band saw, or cannot be transported to the saws. It is the principal tool employed by shipbuilders in wood. It is employed largely in engineers' heavy carpentry for dressing down balks, timber jibs, and timber framings generally.

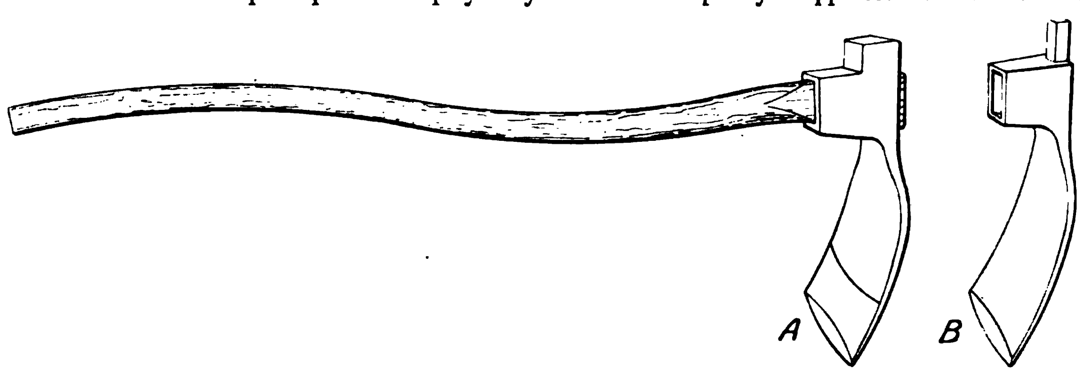

Fig. 13.—*A*. Wheeler's Adze. *B*. Carpenter's, and Joiner's ditto.

Adze Block.—A term sometimes applied to the cutter block of a wood-planing machine. *See* **Cutter Block**.

Aerated Bread Machinery.—The feature by which this is distinguished is the substitution of carbonic acid gas for yeast, which renders handling of the dough unnecessary. The machinery comprises the following:—

Principally, a globular mixer of cast iron, within which the dough is mixed by rotating arms or beaters, under a pressure of six atmospheres. Round this mixer subsidiary apparatus is ranged in the following order. A strongly made wooden cask, or "generator," of oak, receives chalk and sulphuric acid, the combination of which produces carbonic acid gas, as in the manufacture of mineral waters. The gas is conveyed thence by a pipe through water to a reservoir, ready to be pumped into the mixer. Adjacent also to the mixer is a shoot through which the flour is put into the mixer, to be amalgamated with and by the acidulated and aerated water. The dough is received from a tap in the bottom of the mixer, weighed, and sent into the oven, in which the carbonic acid gas passes off.

Aerial Cableways.—*See* **Cables**, and **Cableways**.

Aerial Conveyors.—*See* **Aerial Transportation**.

Aerial Transportation.—Transport by means of ropeways supported at a convenient height above the ground, has advantages which often make it a more suitable method than a road or railway on the surface. The idea is very ancient, but it is only during recent years that it has been much developed and commonly used. It was first recognised as being a very economical and satisfactory method of transporting light loads over hilly, undeveloped country, and over rivers. It was later seen that even in the midst of highly civilised conditions, where roads and railways already existed, it still had advantages under some conditions. More than for anything else, it has been used in mining districts for the conveyance of the products of the mines across rugged country. It is cheaper to erect an overhead cableway for this purpose than to make a road with rails, and the former also has the advan-

Fig. 14.
Bullivant Ropeway at Cape Town, Carrying Merchandise from Ships to the Shore.
The motion of the rope is also employed for working a crane for raising the loads.

Fig. 15.—Bullivant Ropeway used in Constructing Beachy Head Lighthouse.

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tage of being removable from one place to another.

Next to the cheap transport of material across rough country, perhaps the most important application of aerial cableways is for building and excavating operations. For this purpose they are a cheap, and often more efficient means, than an ordinary rigid traveller or a travelling crane. In bridge building, for instance, an aerial cable can be extended across a river, and the materials for the bridge can be deposited where required without having to carry it out in barges, and have the difficulties of current and tide to contend with. In excavating a canal or dock, an overhead cable attached to a travelling tower on rails on each bank will carry the excavators, and obviate the necessity of employing a number of cranes, with rails laid to run them on.

In the loading and unloading of ships, an aerial cable is often more suitable than cranes. The cargo can be deposited or brought from places some distance back from the edge of the dock, or quay wall, and the tower on the dock side can be provided with a boom for running the carriers out over the vessel. In cases where there is no dock, as in Fig. 14, Plate I., a ship may lie at some distance from the shore, and cargo be transported by means of a connecting cable. In the construction of Beachy Head Lighthouse, Fig. 15, Plate I., communication with the shore was by means of cables.

In the coaling of warships at sea, aerial transport is recognised as being the only economic method possible. Except in still water, ships cannot lie side by side. A space of not less than 300 feet is necessary for safety, and the communication must be by cable, means being provided to compensate as much as possible for increased or relaxed tension of the cable.

In large factories and mills, products can often be best conveyed from the floors of one building to the floors of another building at some distance away, by an aerial cable, or a very light aerial railway. This is especially an advantage where constant communication between upper floors of separate buildings is necessary.

Aerial transport is often the only way of conveying material across a railway. In such cases a light guard bridge is generally built beneath the cableway as a precaution against anything falling on to the line.

For passenger transport, aerial cables are used to some extent.

The earliest and simplest type of aerial cableway was an endless rope passing round a pulley at each terminus, and having carriers attached to it, which travelled with the rope. This type is still used, and for very light work is generally considered the more suitable, because of its cheapness. The later type, and the one more commonly used, has a fixed rope which serves as a rail for the carrier to run on, and a separate travelling rope which pulls the carrier along. In the simple type, one rope both supports and carries the load. In the other kind there is a separate rope for each of these purposes, and this gives much greater power and efficiency. Details vary considerably, but all the systems in use may be roughly reduced to the two mentioned. The system best suited for any particular case depends on the conditions, and on the work required of it. With the steel ropes of modern times there is scarcely a limit to the loads that can be transported, and there is no limit to the inclines that can be followed.

For transportation on a level, or up inclines, or for hoisting, motive power is necessary. For carrying loads down inclines the force of gravity alone generally does the work, and in some cases even supplies power for other purposes. On level ground the motive power required is often reduced by making the tower from which the loads are despatched, higher than the tower at the other end of the cable. Cableways of great length are supported at frequent intervals, as in Fig. 16, Plate II., but when necessary very long unsupported spans can be employed. Cableways of comparatively short length, which are supported only by a tower at each end, are made movable, if the work they are intended for requires it. They are thus enabled to cover an immense area of ground. The two towers may be mounted on wheels and travel parallel with each other on lines of rails, or one tower may wheel in an arc, and provision be made for sufficient amount of swivel at the rope connections on the fixed tower. In the fixed rope type of cableway, the

fixed ropes are generally anchored at one end, and kept to a proper tension by counterweights or springs at the other end. The load carriers which travel along the cables are made in forms suitable for the goods they have to carry. When they travel on a fixed rope they are provided with sheave wheels to fit the rope. The carriers are stopped and started by a locking grip which can be made to grip or to release its hold on the hauling rope at any place desired. When carriers are required to stop only at terminal stations, this is generally done automatically. If carriers have to be hoisted and lowered, as in building and excavating operations, ropes are required for this purpose in addition to the traversing rope. All operations are generally performed by one engine situated at the head tower. When two sets of cableways are used, there may be an engine for each, and sometimes engines are employed for moving the towers themselves.

The photos, Figs. 14-16, Plates I. and II., are selected from installations by Messrs Bullivant & Co., Ltd., of London.

The subject of aerial transportation, of which this is a general account only, involves many mechanical details which will be found treated and illustrated under their proper heads of **Cables**, and **Cableways**.

Aerial Navigation. — *See* **Flying Machines**.

Aeroplanes.—*See* **Flying Machines**.

A-Frame.—So called from its general resemblance to the letter A. It is admirably suited for vertical engines, pumps, and crabs, the spread of the legs and the greater mass about the base ensuring stability under working stresses. These frames are made both cast and plated, and in small and large dimensions. Also termed A-Standard.

After-Blow.—The operation of blowing air through the metal in a Bessemer converter after the removal of the carbon, in order to oxidise the phosphorus. *See* **Bessemer Converter**.

Agglomerate Cell.—A modification of the Leclanché cell, in which the negative element consists of a carbon block or plate having blocks of agglomerated carbon and manganese in contact with it. These are prepared by mixing 40 parts of manganese oxide, 55 parts of gas carbon, and 5 parts of gum-lac resin. The mixture is placed in a steel mould and subjected to considerable pressure at a temperature of 100° Cent. The advantage gained is that the porous pot in the older type, which is required to sustain the loose mixture of carbon and manganese oxide, is dispensed with, and the internal resistance of the cell lessened thereby, indiarubber bands being substituted for it.

Aggregate Motion.—Denotes cases in which a moving body receives more than one independent motion concentrated upon it at the same instant of time. The lazy tongs furnishes the most obvious exponent of motion of this kind. In these the sum of the circular movements of the ends of each separate pair of bars is concentrated at the end of the last pair of bars.

The familiar and perennial problem of a rotating cart wheel is another example. The upper portion of the rim of a wheel on a moving vehicle moves with twice the linear velocity of the centre of the axle, while the part on the ground is for an instant at rest. The explanation is that this point is for any moment the fulcrum on which the wheel is turning.

The differential screw is another case in point, in which the aggregate motion is equal to the difference in the pitch of two screws if of the same hand, or by the sum of the pitches if of opposite hands. Other examples are furnished by systems of pulleys, epicyclic trains, and other mechanisms.

Agitator.—A stirrer composed of blades set on a revolving shaft, which has its utilities in numerous industries.

Agricultural Engine. — *See* **Portable Engine**.

Agricultural Machinery.—This comprises the machinery as distinguished from engines used in the processes of agriculture. There are few operations in this connection, for the performance of which highly efficient machines are not displacing hand work and horse power. In modern times such work has to be done on a larger scale and more rapidly than was formerly the case; and in agricultural work, as in everything else, the old methods are being abandoned except for operations on a very small scale. Portable and stationary

engines are very commonly used for supplying power for all purposes. Steam ploughs that cut a number of furrows simultaneously are displacing single-furrow horse-drawn ploughs. The thrashing machine receives the corn as it is reaped and separates the various constituents and ejects them separately from different parts of the machine. All the minor operations in the treatment of the soil are performed by suitable machines, such as cultivators, harrows, rakes, sowers, diggers, rollers. In some cases several operations are combined in one machine. Similarly in the operations of gathering and treating the products of the soil, mowing and reaping machines, swath turners, trussers, presses, elevators, chaff cutters, corn grinders, and numerous other machines are used. Most of these machines are treated under their separate heads.

Aich's Metal.—An alloy patented by Johann Aich of Venice, for guns. It is composed of copper 60, zinc 38·125, and iron 1·5.

There are several alloys having a very similar composition, the principal feature of which is the addition of iron to copper-zinc alloys (*see* **Sterro-Metal**). The cause of the strength of the alloy, formerly obscure, was elucidated in the Fourth Report of the Alloys Research Committee. The iron enters into combination with a low eutectic, forming with it a less fusible compound, so removing the source of weakness. Brass, with, or without the 1·5 per cent. of iron added, has very different tenacities. Thus, two mixtures as follows, were tested at different temperatures. Brass:—Copper 61·2, zinc 38·8 per cent. Aich's metal:—Copper 59·8, zinc 37·9, tin 0·8, iron 1·5 per cent. The tenacity at different temperatures was—

TENACITY PER SQUARE INCH.

Temp. (Cent.)	Brass, Tons.	Aich's Metal, Tons.
20°	20·7	25·6
100°	13·6	22·2
250°	10·4	15·8
450°	3·6	5·1
500°	2·8	4·1

Air.—*See* **Atmosphere.**

Air Belt, Air Chest, or Wind Chest.—The belt put round many cupola furnaces to receive, and distribute the blast through the tuyeres. *See* **Cupola Furnace.**

Air Blast.—*See* **Blast.**

Air Brake.—*See* **Brakes,—Railway.**

Air Caisson.—*See* **Caisson.**

Air Chamber.—The chamber in a torpedo which receives a supply of compressed air for the working of the three-cylinder propelling engines. It occupies about half the length of the torpedo, and the air is forced into it by air-compressing pumps to a pressure of about 1,350 lb. The chamber is of Whitworth compressed steel barely $\frac{3}{10}$ of an inch thick, with convex ends. The pressure is so enormous that the effect of explosions, which are on record, is like that of gunpowder. *See* also **Caisson.**

Air Chest. — *See* **Air Belt, Cupola Furnace.**

Air Chuck.—*See* **Pneumatic Chuck.**

Air Cock.—Cocks used in air vessels, and in compressed air machinery, for relief, and regulation of pressure, &c.

Air,—Compressed. — *See* **Compressed Air.**

Air-Compressing Machinery.—This includes the air compressor, the air receiver, the pumps, and the transmission pipes with the various connections to the machines used.

Air Compressor.—The employment of air under pressure as a motive power has grown enormously of late years. It is a rather more difficult task to say for what purposes it is not used than for what it is. The following is a brief *résumé* of some of its principal applications.

For hoisting machinery of various kinds, for rock drills, for brakes, for riveting, caulking, chipping, for power hammers, sand blast apparatus, moulding machines, for spraying oil in furnaces, for oil lights, for pneumatic transmission, for machinery and motors used in mines, as coal cutters, and locomotives in tunneling, for caissons, for inflating tyres, for testing tubes, for raising submerged vessels, for divers, for ventilation, and refrigeration, for sucking, or blowing loose sand away from moulds, and chips from milling cutters, shavings and chips

from wood-working machines, particles of abraded material from grinders; in sand pump work; and for other applications in numerous arts and industries.

It would seem on first thoughts a simple matter to compress air in cylinders to a pressure of several atmospheres, and store it in receivers for service. But many difficulties arise, due to the elasticity of the air, to the fact that the act of compression produces a rise in temperature, and that the supplies required are constantly varying, even though the compressing pressing cylinders are water jacketed, air receivers regulate the supply, and automatic devices govern the operation of the compressing mechanism. Air compressors are single-acting when they take in air on one stroke only, and force it into the receiver on the return stroke. They are double-acting when they take in and force out air at each stroke. They are single, when the total compression is effected in one cylinder; duplex, or two-stage, when it is done in two cylinders; multi-stage when done in three or four cylinders.

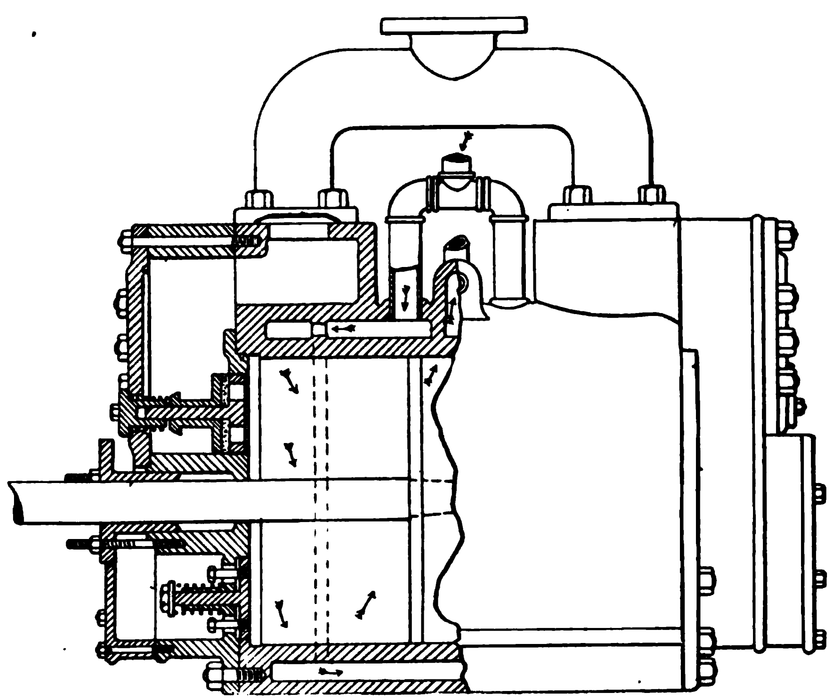


Fig. 17.—The Clayton Air-Compressing Cylinder, with Water Jacket.

apparatus may be working regularly. The storage of steam in a boiler is of a more accommodating character than that of air in receivers. The latter has a close parallel in the accumulator, in which provision is made, as in the best compressors, for automatically checking an increase in supply.

Air compressors are operated by steam engines, connected directly in tandem or otherwise, and they are also belt-driven, or electrically. They are fixed, or portable. Pressures range from about 10 lb. upwards to 2,000 lb. The com-

An advantage claimed for the single-acting compressor over a double-acting machine is that more time is given for cooling the cylinder, because it has twice the time for cooling that the double-acting machine has, which compresses twice during a revolution.

Advantages which the duplex compressors have over the single ones are, that they have no dead points when run duplex; and one section of such a compressor can be disconnected for repairs, while the other continues running. But the principal benefits are those

due to the duplex action, by virtue of which higher economies and easier running are obtainable than on single types.

Compressors are either of average, or of high-class manufacture, D slide valves being employed on the former, and on the latter either piston valves, and cut-off slide valves, adjustable, or Corliss gears. In some of the steam-driven types, the pattern is that of an engine cylinder at one end, and air cylinder at the other, the piston of the first actuating that of the latter

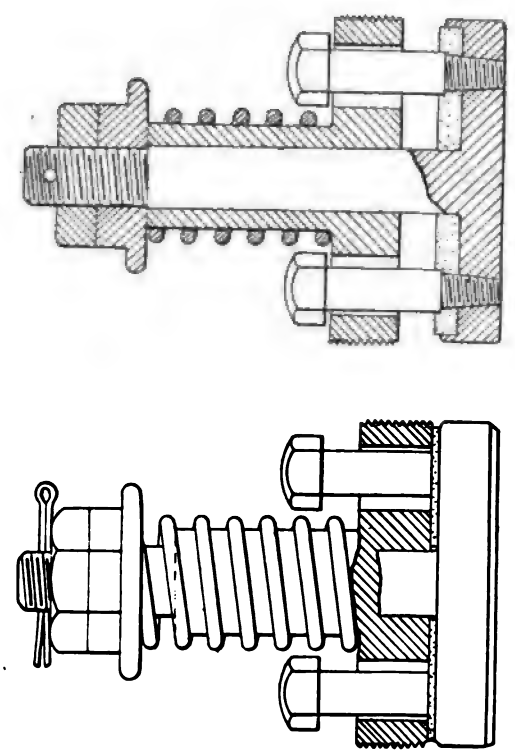


Fig. 18.—Suction Valves of Clayton Air Compressor.

through a connecting rod and crank. In others the cylinders are arranged tandem, and vertically. The belt-driven ones have the appearance of an engine being driven backwards from the fly-wheel, since the belt, driving the latter, reciprocates the piston in the air cylinder through a crank and connecting rod.

The action which goes on in an air cylinder is as follows:—The free air is drawn into one end through suction valves, in consequence of the vacuum created by the receding movement of the piston. The same movement compresses the air in that portion of the cylinder in the direction of which the piston is moving. The suction end for that movement becomes thus filled with air at atmospheric pressure. This complete filling is important from the point of view of efficiency, and it depends on the number and size of the suction valves. These are properly placed in the cylinder ends or "heads" in horizontal compressors. On the return stroke of the piston this air is compressed, and sent out through discharge valves, and thus

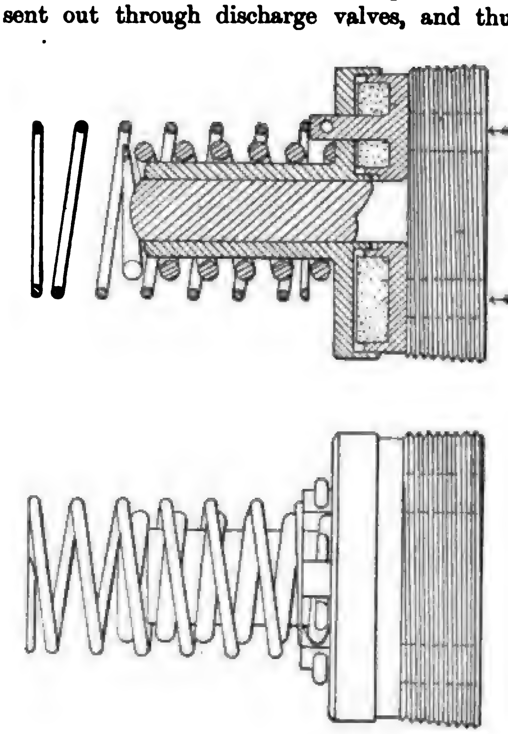


Fig. 19.—Discharge Valves of Clayton Air Compressor.

two compressions are given with every rotation of the fly-wheel.

Because it is important to keep the air temperature as low as possible, the cylinders are water jacketed. The hottest part of the cylinder is the top. Hence the design embodied in the Clayton cylinder, Fig. 17, is intended to ensure ample circulation at that locality. The water enters at the top of the jacket, is circulated thence to and around the ends of the cylinder, and back to the top, to be there discharged.

Air may be withdrawn from the atmosphere directly, or through an inlet connected to the outside of the engine-room, where it is cooler, and free from dust, the latter being very important as lessening the wear of the valves, rods, pistons, &c. Taking air from outside the engine-room is a matter of more importance in cold than in warm countries, and in winter than in summer. It is stated that for every five degrees lowering of temperature there is a gain of 1 per cent. in efficiency. A wooden inlet pipe serves the purpose.

Valves are generally of the lift type, both being in connection with the interior of the cylinder, one set drawing air, the other discharging. Figs. 18 and 19 illustrate respectively the suction and discharge valves of the Clayton compressor. Several of these are placed in the cylinder heads. They are of the lift type, having the faces protected with discs, slightly elastic. The safety stems or guard bolts steady the valves, preventing their dislodgment. The spring cushions the valve movements. The faces of the seatings are level with the interior faces of the cylinder heads.

In the piston inlet type of the Ingersoll-Sergeant Co., the valves are located in the piston, Fig. 20. There is a tube attached to the rear end of the piston, which moves with the latter, and through which the air is conveyed to the interior of the piston in the first place. The chamber in the piston body is covered by two steel ring valves of large diameter, which open and close in response to the movements of the piston, the amount of opening or lift being but ¼ inch. The valves have no springs, their movements are easy and quiet, and the wear on them is not apparent for many years. The discharge valves at opposite ends of the cylinder communicate with the delivery chamber and pipe below.

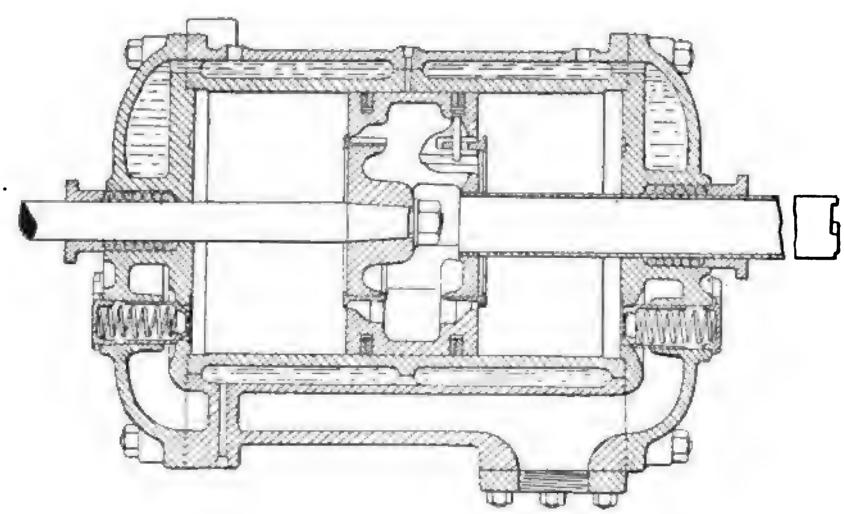


Fig. 20.—Ingersoll-Sergeant Piston Inlet Valves.

Two-stage, or compound compressors, and multi-stage compressors, are used for high pressures. This type is adopted generally for pressures ranging from about 80 lb. to 2,000 lb. per square inch. The mechanism involves two or more cylinders, low and high respectively, through which the air passes in succession. Coming into the low pressure first, it is compressed to one stage, whence passing into the second, or succeeding cylinders, it is raised to the maximum pressure. An intercooler is placed between the low and high pressure cylinders. The air passing through this loses nearly all its heat before it enters the second cylinder.

The drawings, Figs. 21-23, show a single-stage air compressor of vertical type, by Mr Peter Brotherhood, of Westminster. This design is preferred by the firm on the ground that the

wear of rods, pistons, packings, &c., is less rapid than that of horizontal machines. Pressures up to 80 lb. per square inch are provided for in single-stage machines. Higher pressures are effected in double, or multi-stage types. Around the general design in these figures several modifications are effected. As this is a single-stage compressor, there is, of course, no inter-cooler. The machine shown is fitted with a steam cylinder above. In some cases this is omitted, and driving takes place from a motor, or by gear wheels. The two and three-stage compressors have two and three cranks respectively.

The general construction of the compressor shown is as follows:—The air cylinder below is carried on a casting which forms an enclosed crank chamber, with doorways, and containing provision for automatic lubrication. A distance piece bolted to the top of the air cylinder receives the steam cylinder, and the pistons of both move in unison, on one rod which is secured to the crosshead below, working in circular guides, a connecting rod thence operating the crank shaft. The latter has a fly-wheel at each end, notched in the rim to permit of barring round the compressor when starting. When intercoolers are fitted, as to the compound compressors, these are placed in the lower part of the crank chamber, and the cooling water circulating through this, keeps the lubricant in the chamber cool.

An eccentric on the crank shaft actuates the balanced piston valve seen at the side of the steam cylinder. The cylinder is lagged with sheet steel, both around the sides, and on the covers. Compound steam cylinders are fitted to the two and three-crank machines.

The air cylinder is double-acting, excepting the two-stage single-crank single-cylinder type, the air being compressed in the upper and lower parts of the cylinder alternately. Each of the air valves is fitted in a separate chamber (compare with the sectional detail, Fig. 23), placed radially round the air cylinder, the delivery valves being at the front, and the inlet valves at the rear.

The valves have the form of flat discs pressed against their seatings by light spiral springs. The fact that they are very light is to be emphasised, since they act promptly, with the

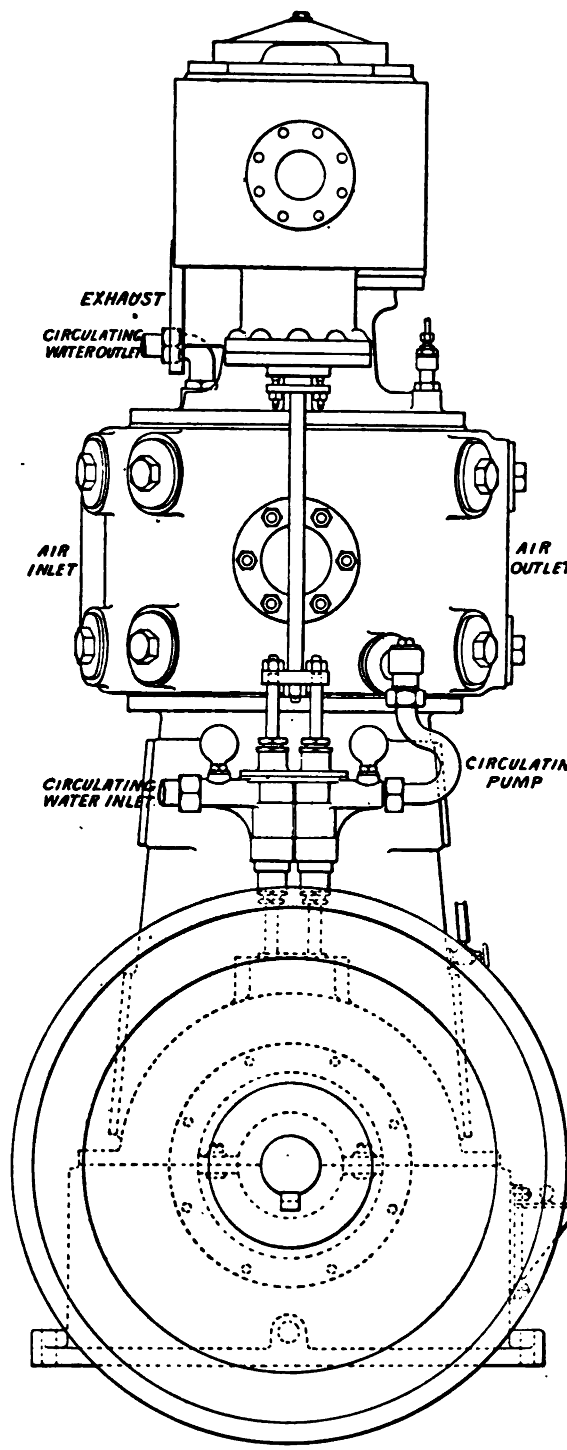


Fig. 21.—Double-Acting Vertical Air Compressor. (Air Cylinder, 19 in. by 8 in.) Mr Peter Brotherhood, London. (Elevation.)

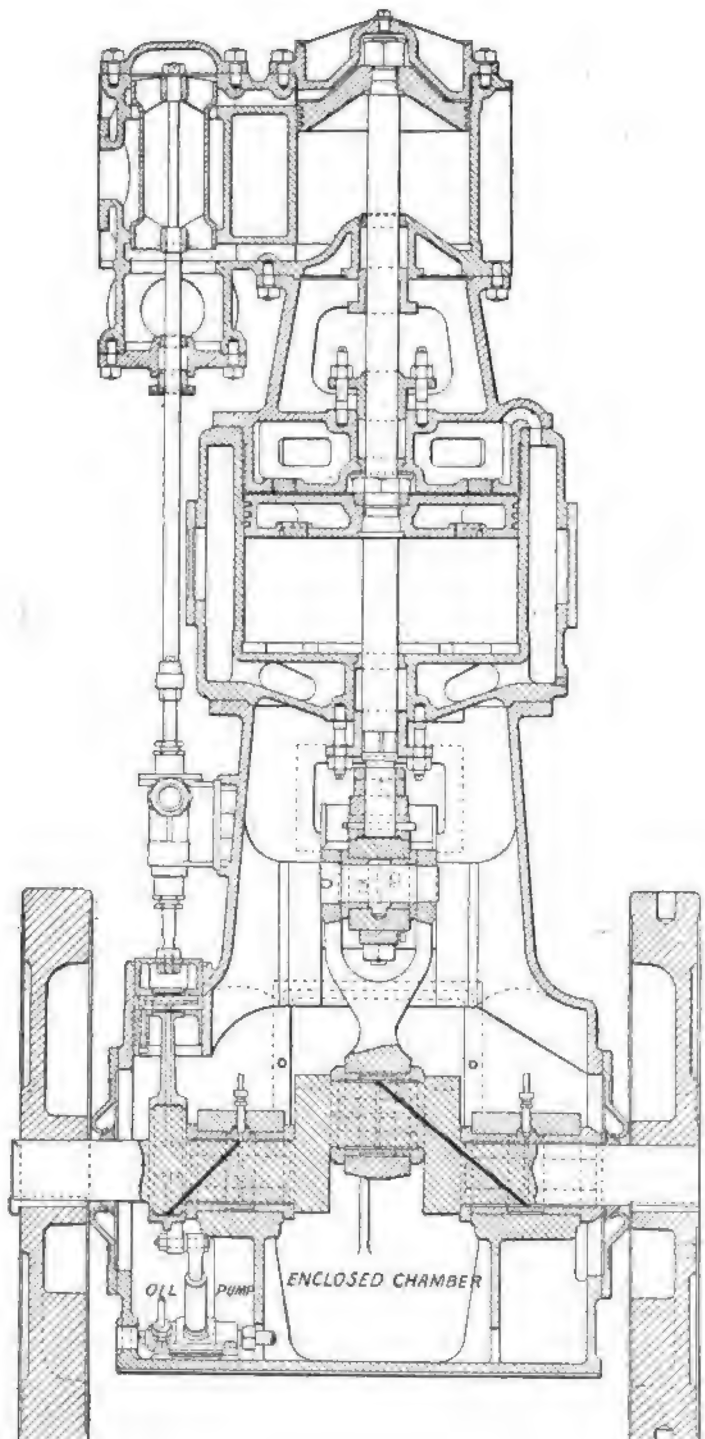


Fig. 22.—Double-Acting Vertical Air Compressor. (Air Cylinder, 19 in. by 8 in.) Mr Peter Brotherhood, London. (Sectional Elevation.)

minimum of noise, and wear and tear. They can be removed with their seats and springs by unscrewing the caps, and removing the guards seen in Fig. 23. The valves both for inlet and discharge are similar, but the position of the discs is reversed. Joints are ground, avoiding the use of packings.

In the two-stage single-crank single-cylinder machines, the compressions are carried out in one cylinder, fitted with a trunk piston. After the air has been compressed in the upper part of the cylinder it is passed through an intercooler and admitted to the space below the piston, between the cylinder and the trunk, where it is finally compressed on the down stroke of the piston.

The firm prefers, where possible, to have two cylinders for two-stage compressors, instead of making use of an annulus between trunk and cylinder. The latter has the disadvantage of exposing a greater length of packing rings, &c., to greater difference in pressure, and is not so economical or durable.

Oil is supplied under pressure from a pump in the bottom of the crank chamber actuated by an eccentric on the crank shaft, and seen in Fig. 22. The chamber forms the oil reservoir. Its interior is painted with several coats of white enamel which protects the metal from the action of the mineral oil, and casts a reflected light on the interior on the removal of the doors, for examination. There is an oil pressure relief valve, and a pressure regulator and equaliser. The oil is filtered through copper gauze of fine mesh, removable for cleaning. For compressors running continuously, two of these strainers are fitted, so that either one can be removed and cleaned, leaving the other in place the while. Governors and auto-

matic pressure regulators are fitted to maintain the air pressure in the receiver nearly constant.

These compressors are only used for moderate air pressures up to about 500 lb. per square inch. For higher pressures many varieties of three and four-stage types are made.

The Brotherhood compressors are tested from the quantity of air actually pumped into a reservoir of predetermined capacity, a method which gives the net results after all losses due to the clearance volume, imperfect action of the air valves, leakage past the piston, or loss due to increase of temperature during compression.

The "Sentinel" air compressors by Messrs Alley & Maclellan, Ltd., of Glasgow, are of style; that is, a piston valve controls the air inlet, and the discharge is actuated by valves which are practically unbreakable. The governor gear is of simple but effective design, and not liable to get out of order easily, the action of the same being; that on a rise of 2 lb. above the working pressure, air is admitted to the controller, which shuts an equilibrium valve situated on the air inlet. Thus the air supply can be practically cut off, and the compressor run on a partial vacuum, which is economical as regards power absorbed when the machine is running light.

An intercooler of compact design, but of large surface, is arranged in the base plate, and the air, which is cooled to a certain extent by the

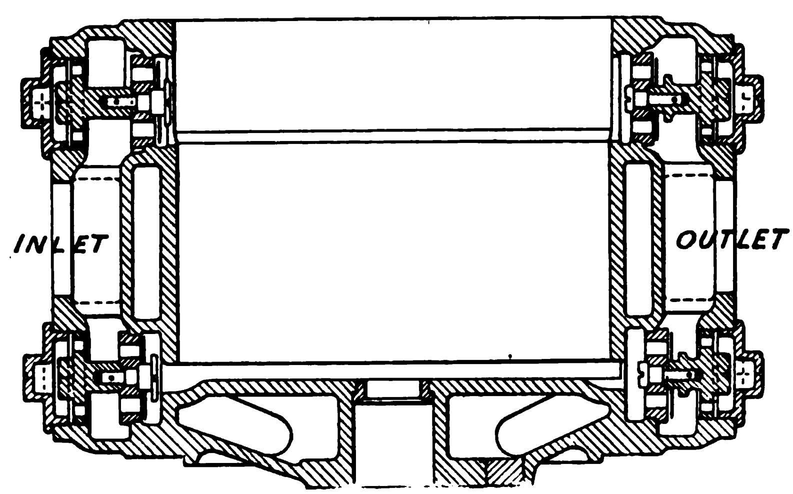


Fig. 23.—Enlarged Transverse Section through Air Cylinder of Brotherhood Compressor, to show Valves.

vertical type. These machines, which are the outcome of many years' experience, rank high in both mechanical and volumetric efficiency. The special features of the design, Fig. 24, are the following:—

The complete machine is enclosed, and thus no dirt or grit can possibly get at the bearings to cause trouble through heating. The lubrication is of the forced type, the oil pump being driven from one end of the crank shaft, and a filter is fitted which is of easy access, and can be cleaned in two minutes; this, with bearings of exceptionally large surface, ensures good running under all conditions. The valve gear is of the combined mechanical and automatic water jackets that are round the cylinder, passes from the LP. cylinder (in compound types) down a pipe to the cooler, where the pipes are arranged so that the air must pass backwards and forwards a number of times before reaching the HP. cylinder for final compression.

The floor space occupied has been reduced to a minimum, and the designs have been so arranged that either belt, motor, or steam can be used for driving purposes. In the latter the steam cylinders are arranged on top of the air cylinders, and when a machine of larger capacity is required, Messrs Alley & Maclellan have special crank cases to take two, or three cylinders as may be required. Thus, for a 400 cubic feet

machine it would be single-crank, for 800, double, and for 1,200, three-crank, so keeping down the height, and adding to the stability of the machine as the power increases.

The Reavell compressor, Fig. 25, is a type by itself. The name "quadruplex" is given to it because it has four cylinders arranged radially in a casing. These are of circular shape, water jacketed, by means of which four deliveries of air are given during each revolution, the effect being that of four separate single-acting air compressors. Each cylinder has its own trunk piston, and the four connecting rods are driven by a common crank pin. The delivery is practically continuous, since there are no reciprocations, and the speed is high.

Portable air compressors are made for the purpose of supplying pneumatic tools and machines, the use of which is spread over large areas, so avoiding the employment of impracticable lengths of tube. These are of two types, the steam, and the electrically driven.

The steam-driven portable compressor may have for its basis an ordinary portable steam engine, to which the compressor and receivers are added. In the Davey-Paxman type the compressor piston is driven by the tail rod of the engine piston, which brings the air cylinder directly over the fire-box. The engine and air cylinder are flanked by two horizontal air receivers having connecting pipes coming from the delivery valves above the cylinder. The circulation of the cooling water in the air cylinder jacket is maintained by a plunger pump operated by an eccentric on the crank shaft.

Other portable compressors driven by steam

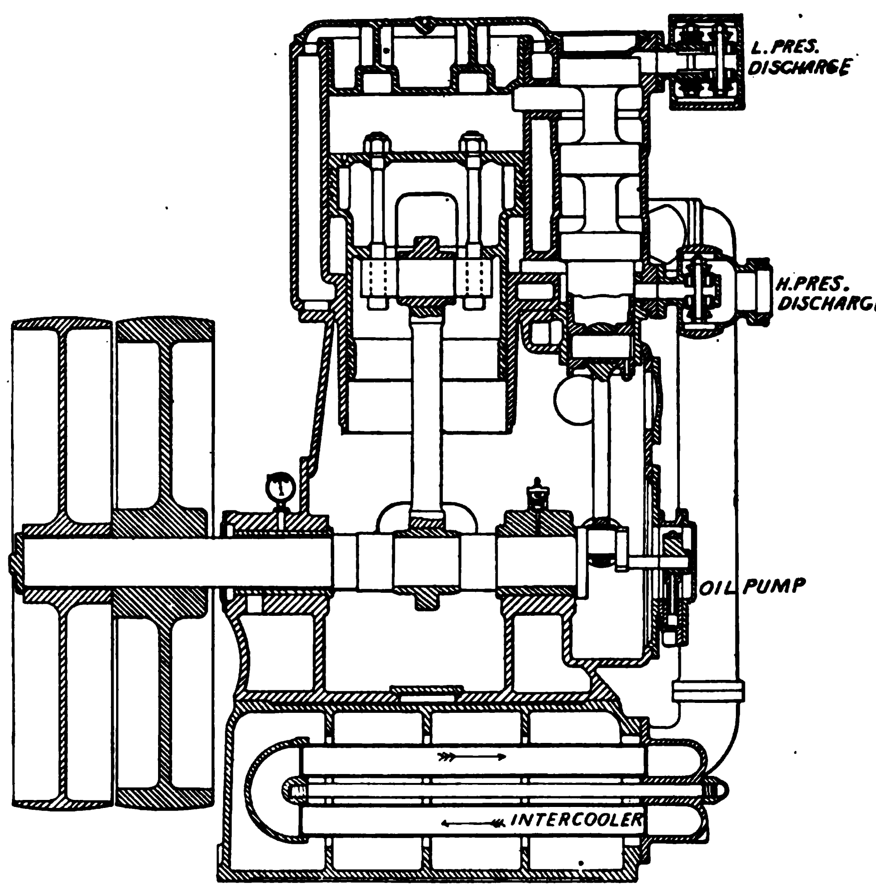


Fig. 24.—Vertical Single Cylinder Two-Stage Air Compressor. Alley & Maclellan, Ltd., Glasgow.

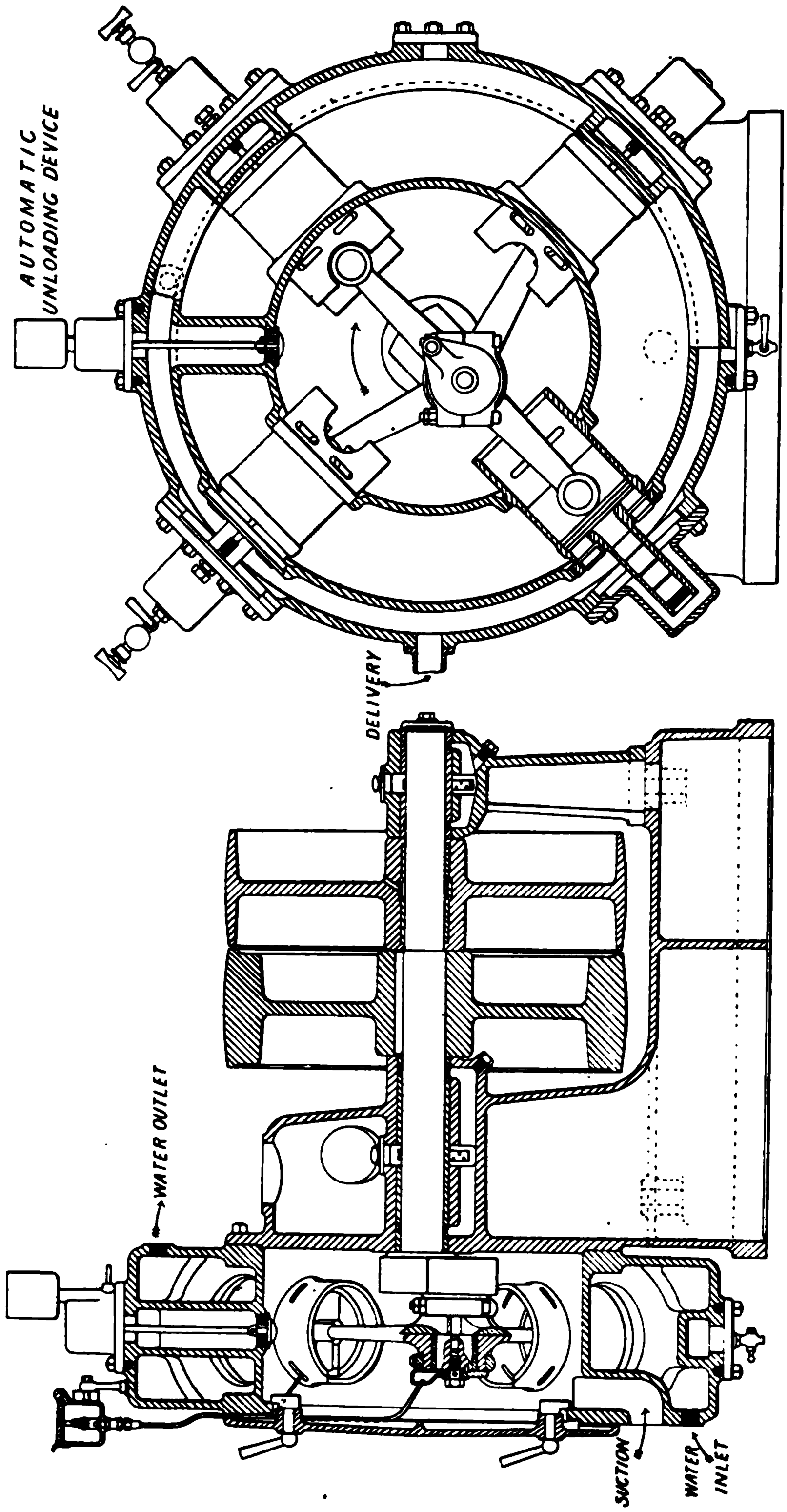


Fig. 25.—Quadruplex Single-Stage Air Compressor. Reavell & Co., Ltd., Ipswich.

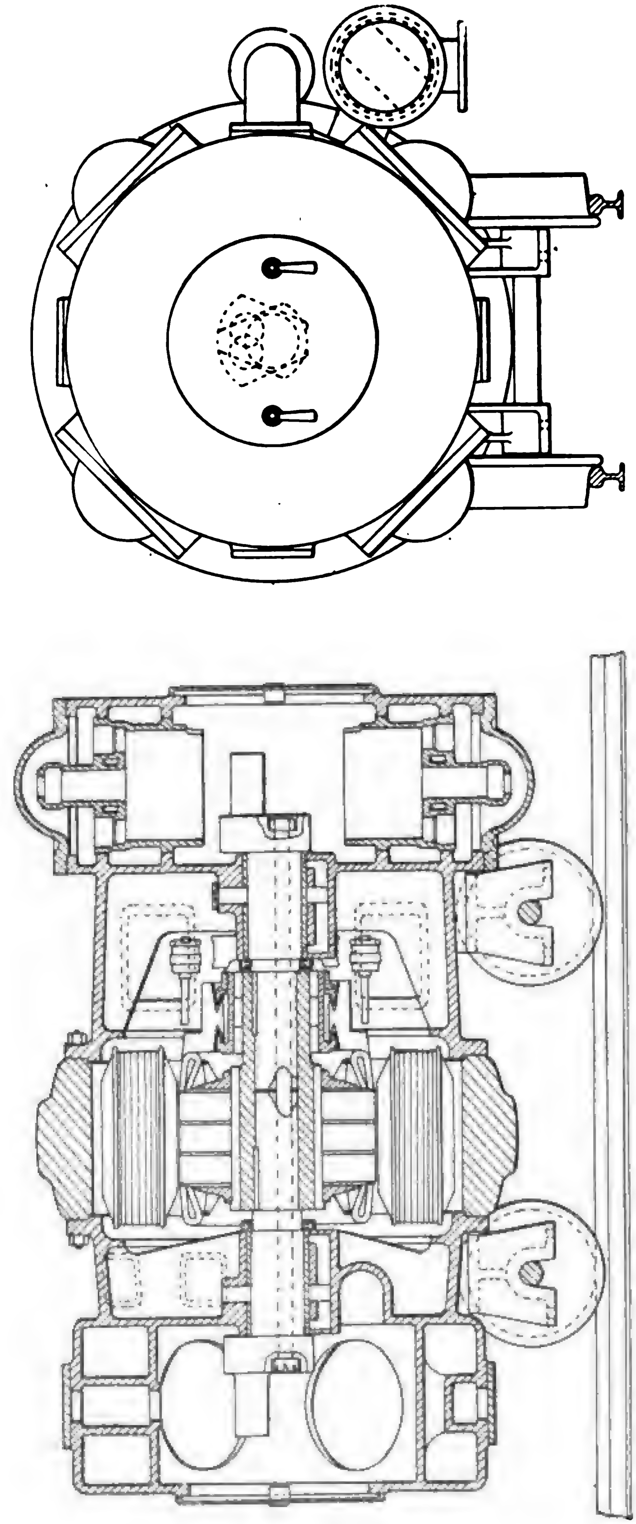


Fig. 26.—Sectional Arrangement of Direct-Coupled, Double-Ended, Electrically Driven Portable Mine Compressor
Reavell & Co., Ltd., Ipswich.

Fig. 16.—A Group of Nine Cableways at Bilbao. Total carrying capacity, 2,500 tons a day.

Fig. 27.—Direct-coupled, Double-ended, Electrically-driven Portable Mine Compressor.
(Reavell & Co., Ltd., Ipswich.)

To face page 60.

are mounted on a truck base with wheels, and a high-speed engine on the bed plate drives the compressor through gear wheels.

The Reavell rotary compressor lends itself admirably to electric driving. In the smaller sizes the motor drives the compressor through gear wheels, but in the larger it is coupled direct. A small reservoir only is necessary, because of the high speed of rotation, and the fact that there are four deliveries of air per revolution. The sectional view of a Reavell portable mine compressor is given in Fig. 26, and a general view of the same by the photograph, Fig. 27, on Plate II.

The subject of **Compressed Air** will be treated under that heading. For the present, therefore, we are only concerned with the bearing of that subject on the design of air compressors.

The first thing to be guarded against in the design is the prevention of useless work in the transformation of energy into heat, or in other words, the aim is the production of the largest volume of air under pressure, with the smallest expenditure of fuel.

The difference between the adiabatic and isothermal quantities of work done is the amount of work that is turned into heat in the work of compression. Practically adiabatic compression alone is considered in design, partly because air is so nearly a perfect gas that nearly all the work done upon it appears as heat, and partly because when high compression is necessary, it is produced in two or more stages. And this is in spite of the fact that the cylinders are jacketed with circulating water to lessen as far as possible the loss of heat through the cylinder walls.

Beyond about 60 or 80 lb. per square inch, when two-stage or multi-stage compression is adopted, with intercoolers (which take the form of receivers, or of tubes), the work of compression is divided equally between the compressing cylinders. These are designed either for the volume, or weight of air to be taken in, or of that of discharge. If for admission, the speed and piston displacement and the volume of free air at atmospheric pressure at 13 cubic feet to the pound are the factors required. If for discharge, the relation becomes that of a volume of 1 lb. of free air at atmospheric pressure to that of a volume of 1 lb. of air when compressed adiabatically at the given pressure.

The reason for the water jacket is clear from the fact that as the temperature of the air rises under compression, the work of compression is increased proportionally, because the heated air is attempting to expand against the piston pressure and to do external work. The necessity for intercooling is also explained in the same way. The aim in intercooling is as nearly as possible to reduce the temperature of the outlet air from one cylinder to the atmospheric temperature, at the inlet of the succeeding stage.

The water jacket is only a crude device, but it is the best attainable at present. Air is a bad conductor, and loses its heat slowly. Only a small portion of the volume of the air comes in contact with the walls of the jacket; hence, in large cylinders the jacket economy is less than in small ones.

End clearance in cylinders is reduced to the minimum, because any volume of air left there expands on the return stroke of the piston, and checks the admission of the volume of free air. If there were no clearance, which is impracticable, there would be no limit to the pressure that could be employed in one cylinder, except that of the heat generated, or the strength of the cylinder.

The governing of compressors is a matter of much economical importance. If less air is being used, as frequently happens, than the compressor is delivering, the surplus goes off through the safety valve of the air receiver, and represents so much wasted. The object of governing is to prevent this waste by causing the compressor to respond to the demands made upon the supplies stored in the receiver.

Governing is done in two ways, either by reducing the speed of the compressor, though still allowing it to supply reduced quantities of air to the receiver, or by reducing speed, and stopping the supply of air entirely. The objection to the first is that the air is constantly escaping from the safety valve of the receiver. In an ideal regulating device the air supply to the air cylinder is cut off. In the Ingersoll-Sergeant machines this is effected by the opening of a passage between both ends of the air cylinder,

by which air is admitted on both sides of the piston, tightly closing the inlet valves. At the same time the supply of steam to the engines is automatically throttled to a stage which just permits the engine to keep turning at a slow speed sufficient to overcome friction or dead points.

The precise functions and forms of governors therefore vary. In those fitted to steam-driven compressors the governor operates on the steam supply pipe, regulating the volume delivered to the cylinder or cylinders. The governor can be set for a particular air pressure desired. In belt-driven compressors the governor opens a relief valve. A useful form is that of a combined speed and pressure governor which combines with the air-pressure governor to prevent racing when exceptionally heavy demands are made upon the air supply, which often occurs in intermittent service.

Governors should not be set to stop the compressor entirely, but adjusted to merely keep the cranks moving over dead points. If a compressor stops on the centre it may fail to respond to the governor when a demand is made on the supply. In duplex compressors where there are no dead points the adjustment must be just sufficient to overcome the friction of the moving parts.

The fact that the demand for air is nearly always of an intermittent character, though to a greater or less extent, renders it desirable that compressors should be driven independently of all other machinery.

If air compressors have to be used in mountainous districts, allowance must be made for loss of efficiency due to the lower pressure of the atmosphere. *See* **Barometer.**

Air Cooling. — *See* **Air Compressor, Petrol Engines, Ventilation.**

Air Cushion.—The volume of air under compression in an air vessel, and by which the pulsations of the water are checked. *See* **Air Vessel.**

Also a small volume of air imprisoned and compressed behind a retreating piston in pneumatic mechanisms. It is obtained by blocking the further escape of air just before the termination of the stroke. The result is similar to that of cushioning obtained in engine cylinders, and for the same reason, to prevent shock, and act as a spring buffer in bringing the piston to rest.

Air Cylinder.—The cylinder of a blowing engine through which the air is compressed.

The cylinder of an air compressor, in which the air is compressed by the piston.

Air Drills.—*See* **Pneumatic Drills.**

Air Engine, or Air Motor.—The term is given to a type which is actuated by compressed air, and used both for hoists and travelling cranes. Two double oscillating cylinders have their axes set at right angles in an air-tight case, the air ports being controlled by a slide valve operated by the oscillations of the cylinders. Reversals are effected by an eccentric motion attached to a hand wheel, by which the direction of movement of the valve is controlled. A small quantity of oil is enclosed in the case, and the revolving crank is thus lubricated, and it also dashes oil on the valve seats. *See also* **Compressed Air Locomotives, Hot Air Engine.**

Air, Free.—Air at atmospheric pressure. *See* **Air Compressor, Compressed Air.**

Air Friction.—This has its applications in the loss of pressure due to the transmission of air through long pipes, and to the ventilation of mines.

The loss of pressure in passing through pipes is slight. The only effect is to lessen the pressure, and not the volume. Sharp bends must be avoided, as in water pipes, and for the same reason.

Globe valves reduce pressure considerably, and elbows and tees rather less. A globe valve inserted in a 4-inch pipe is equivalent to increasing the pipe length by 20 feet. The Ingersoll-Sergeant formula is :—

$$\text{Additional length of pipe} = \frac{114 \times \text{diam. of pipe}}{1 + (3{\cdot}6 \div \text{diam.})}$$

Using elbows, and tees, the reduction of pressure equals two-thirds that of globe valves, so that these in a 4-inch pipe would be equivalent to increasing the length of the pipe by 13 feet.

The experiments of M. D. Murgue in mines proved that the smoothness or roughness of

the passages exercised considerable influence in producing friction, as did also that of relative areas, and of curves. The following coefficients were deduced, being taken as the pressure, or inches of water pressure necessary to circulate 1,000 cubic feet of air per minute through a passage, the frictional surface of which is equal to 1 square foot. The results given in the first series are averages of several experiments on different kinds of passages. For arched passages the average coefficient is 0·00033, for inclined ditto 0·00094, and for timbered passages 0·00156.

Taking passages under these several conditions, each of 36 square feet in area, and 437 yards long, the ventilating fan must produce an average pressure in the first case of 1 inch of water, in the second of $1\frac{1}{2}$ inches, and in the third of 2 inches. In other words, the pressure produced being constant, there would be 46,109 cubic feet per minute circulating in an arched passage; 38,014 in an inclined one; and 33,103 in a timbered one.

The coefficient of friction increases also with reduction of area. While for an arched passage of normal area it is 0·00033, it is 0·00055 for one of small area; while for an inclined passage it is 0·00094, it is 0·00122 for one of small area; and while for a timbered passage of normal area it is 0·00156, it is 0·00238 for one of small area. Lastly, while the average coefficient for an arched passage with a straight drift is 0·00033, it rises to 0·00051 in one slightly sinuous, and to 0·00062 in one with continuous curvature.

Air Furnace.—*See* **Brass Melting Furnace, Reverberatory Furnace.**

Air Gap.—The space left between the armature and the magnets of a dynamo, or motor. It varies from about $\frac{1}{32}$ to $\frac{1}{4}$ inch, and its object is to prevent temperature from rising too high.

Air Gate.—A term often applied to the opening through which gases escape during the pouring of a mould. It is more commonly termed a Riser, and its functions will be found described under that head.

Air Governor.—*See* **Air Compressor.**

Air Hardening.—*See* **Hardening, Tempering, High-Speed Steels.**

Air Hoist.—An overhead hoist in which the hook is operated directly by compressed air actuating a piston in a cylinder above. The height of lift is therefore identical with the stroke imparted to the piston, which may be full, or partial only.

The difficulty which interfered for a long time with the extended use of these hoists was that due to the elasticity of the air, which, unlike the practically solid, incompressible medium of water, was the cause of jerky movements, following on sudden changes in the load. These objections have been removed in the best hoists by governing devices, which are of different kinds.

Another objection to the direct-acting hoists is that they hang down in the way, and must be taken back to the wall, when not in service. But in modern systems, an overhead trolley installation is generally erected, over the areas to be served by the hoists, and the latter are run along by trolley wheels on the tracks. Often, too, hoists are fitted on the horizontal jibs of swinging wall, or pillar cranes. In other cases the air cylinder is fitted between the pillar, and the movement of the piston operates a racking carriage on the jib, through a chain, and from which the hook depends in a bight of rope passing round a snatch block. Sometimes the cylinder is laid in a horizontal position, when the vertical one would interfere with the work going on.

The advantages of air hoists are their lightness and portability, and by comparison with hydraulic hoists, the avoidance of risk of freezing, and fracture consequent thereon.

The methods of governing adopted are of two kinds, the use of automatic valves supplementing the main air valve, and the employment of a non-compressible fluid, as water or oil. Each maker has his own devices for governing, and for ensuring safety in working. In some cases an automatically acting valve opens if the air leaks, and this maintains the load at a constant height so long as the main valve is not opened. Sometimes a variable load, which occurs when pouring metal, is kept stationary by an automatic valve. In a water-governed hoist a small volume of compressed air acting on a large volume of water (or oil)

in a closed cylinder operates the plunger in another cylinder. In another case an air cylinder operates on a column of water which actuates the hydraulic cylinder. In another, the air is controlled by oil in the piston rod, made hollow for the purpose, and fed from a reservoir, the supply being regulated by valves.

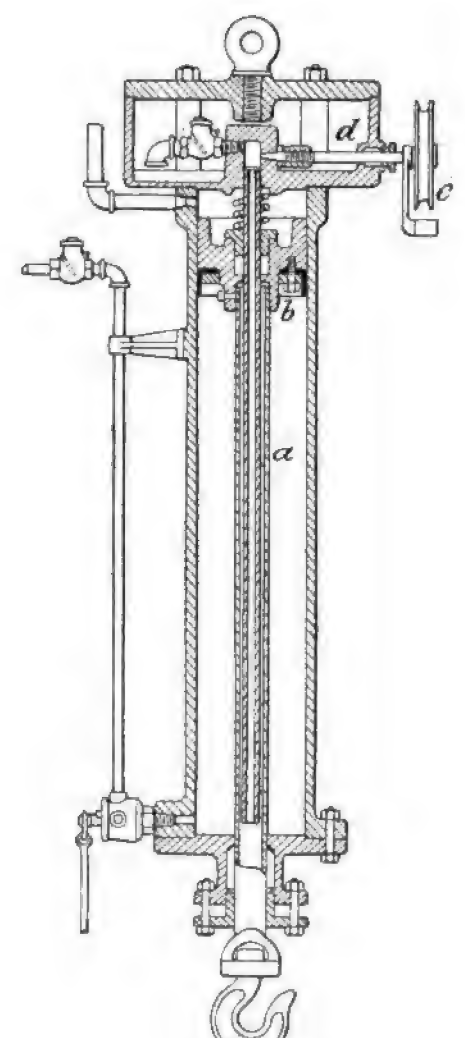


Fig. 28.—The Ridgway Oil-Governed Air Hoist.

That these devices have in one way or another got over the objections to jerky movements is well illustrated by the fact that air hoists are used in large numbers in foundry work, in delicate lifts, where a sudden jar would result in strained and broken moulds.

The structure of the Craig-Ridgway hoist, governed by oil, is as follows (Fig. 28):—The piston rod *a* is made hollow, to take a hollow bar which is fastened to the top of the cylinder —the latter being shaped as a reservoir—and which supports the weight of the hoist and its load. It passes through a bush in the piston *b*, and the piston packing slides closely over it. A dependent chain from the pulley *c* actuates a valve, which regulates the flow of oil between the receiver *d* and the rods. When the piston is at its lowest end, the rod *a* is filled with oil. Then the entry of air into the cylinder and the opening of the valve permits the oil to escape into the reservoir as the piston ascends. The amount of opening of the valve controls the rate of movement.

An air hoist of another type—the "Sentinel," by Messrs Alley & Maclellan, Ltd., of Glasgow —is shown in Fig. 29. Adequate provision is made in this for all contingencies. The air is admitted at the nozzle *a*, seen near the top of the cylinder, whence it passes down to the spring valve *b*, seen below. Should the air supply fail while a load is in suspension, or the hose twist, the check valve at the top closes, preventing escape of air from the hoist, and so holding up the load. The operating valve is moved by a cross arm *c*, *c*, with dependent chains, an index plate *l* showing which chain to pull to lift or lower. Two valves in the bottom cylinder cover serve to save air, and to balance. These are operated by means of the adjustable collar *d*, which is set to suit the height at which the load has to be lifted. As the load rises, the collar comes in contact with the sliding sleeve *e*, held down by a helical spring. One arm of the sleeve then operates a piston valve *f*, and the other arm a poppet valve *g*. When *f* rises, it shuts off the air supply, and the hoisting stops. If the load is reduced, as when pouring metal, *f* rises a little higher, and then *g* is opened, allowing a little air to be discharged from the cylinder, but leaving enough pressure within to balance the lessened load. If a load is suspended for a while, and air escapes, the piston descends, and *f* admits more air. When *f* is closed, the exhaust from the main outlet is closed. But on reversing the arm *c*, for lowering, air comes out through a by-pass connected with the

valve *b*, until the piston has descended a little way, when the larger volume of air escapes through the main outlet. An air cushion is formed at the upper end of the cylinder by drilling a small hole *i* shown there. The piston blocks this hole when at the upper end of its stroke, enclosing the air imprisoned above it, which thus cushions the piston. Note should be for making hydraulic leathers to permit of the escape of the air, which, if imprisoned, would prevent the closing of the moulds. The precaution is also necessary in many other kinds of articles where a close fit would prevent the air from getting out. Cone friction clutches are a case in point, and these must have one or two small holes drilled to allow them to close.

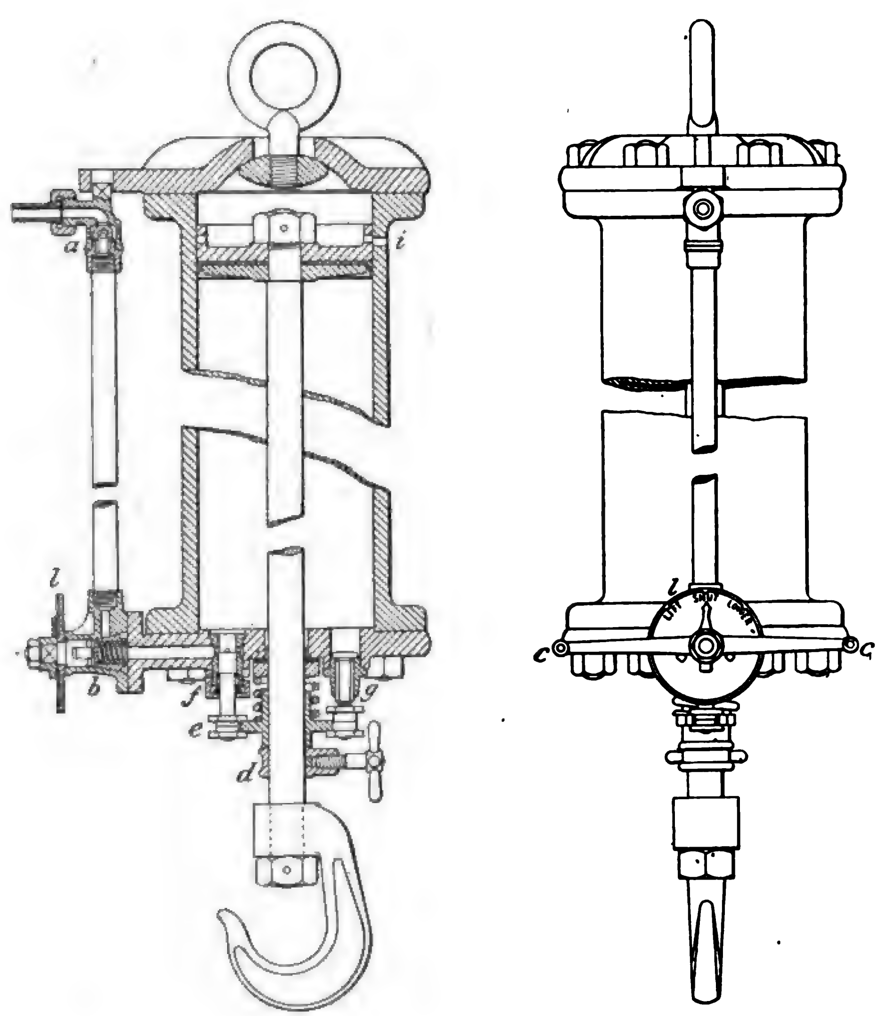


Fig. 29.—The "Sentinel" Air Hoist.

made in conclusion of the spherical bearing for the eye of the hoist, by means of which the hoist can easily be swung to an angle.

Air hoists are also actuated by air motors, having oscillating cylinders. *See* **Air Engine**.

Air Holes.—These are drilled in the moulds

Denotes also the holes which admit air to a gas-fired furnace.

Air Hose.—*See* **Hose Pipe**.

Air Leakage.—The leakage of air in compressed air plants and in pneumatic machinery would result in a serious loss of power, if the

precaution were not taken of carefully grinding all valves in their seats, and making a good fit of the various unions.

Air Lift.—The system of lifting water from artesian wells by the help of compressed air. The principle and practice is as follows:—

The delivery pipe (*see* Fig. 30), which goes nearly to the bottom of the well, encloses a much smaller pipe, down which compressed air is forced. (In some cases the air pipe is brought down outside the delivery pipe, and its nozzle introduced at the bottom of the latter.) The result is that the pressure of the air fills the delivery pipe with alternate bands or zones of water and air. As the total pressure thus produced is less than that due to the head of water in the well out-

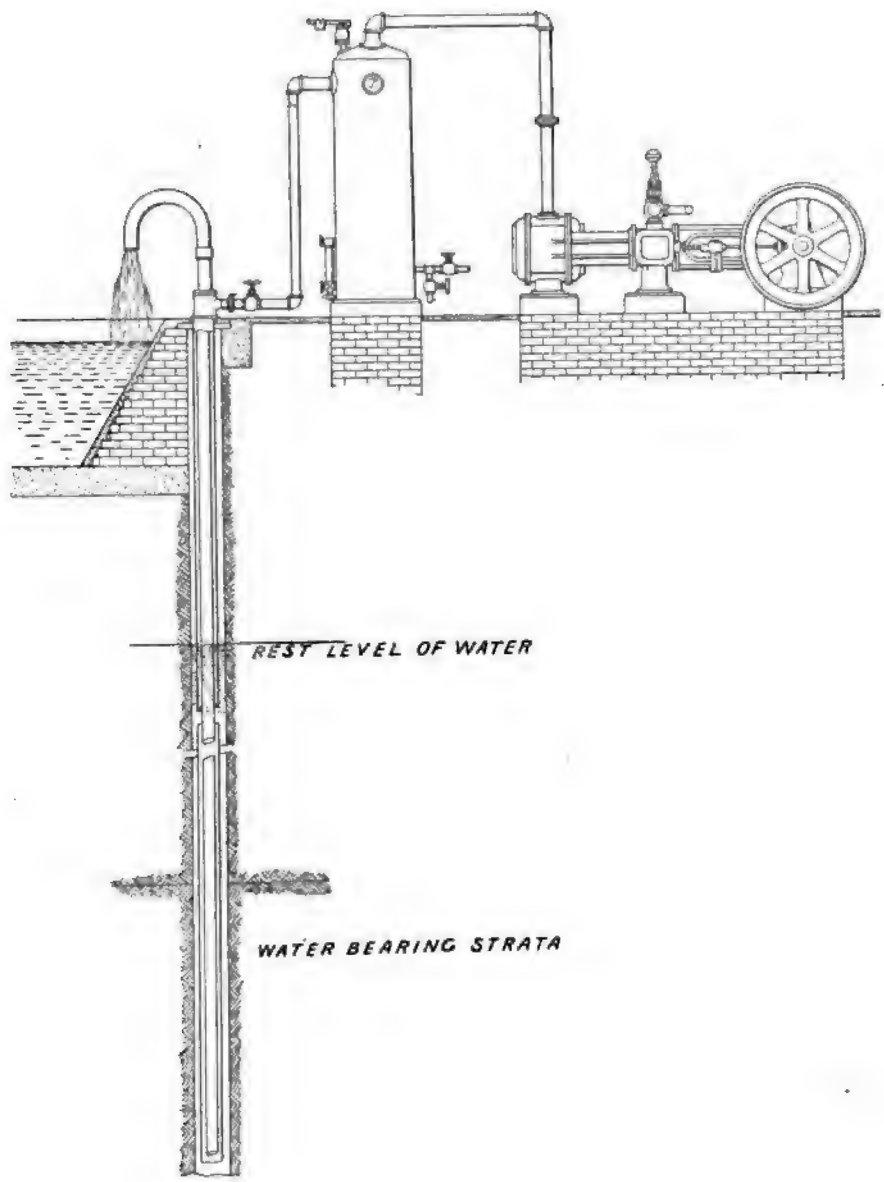


Fig. 30.—Air Lift. By John Thom, Patricroft.

side the pipes, the water rises in the delivery pipe.

As the lifting force is that due to the difference of the head of water outside the pipe, and that due to the broken water within, the depth of immersion must be proportioned to the height to which the water has to be lifted. The depth to which the immersion must be made is, however, found to vary rather widely. Mr W. H. Maxwell gained the most economical results at Tunbridge Wells when the ratio was 3 of immersion to 1 of lift at the start, and 2·2 to 1 at the finish, the difference being due to the sinking of the water from rest level to pumping level. Tests of some Continental air lifts go down lower.

$$X = \frac{A \times B}{142}$$

where X = cubic feet of free air per minute.

A = gallons of water required per minute.

B = lift of water in feet.

It is not economical to instal air-lifting systems in all situations, or under all conditions. It is essential that the difference between the level of the water at rest and the level as reduced by pumping should not be excessive. The ratio of the immersion of the air pipe to the lift must be adjusted to these, and not vary much.

The great advantage which this system has, is that it does away with movable pumps, foot valves, &c., underground, which are liable to need repairs, and to become choked with sand, &c. All the machinery is above ground, where it is open to inspection. It is admirably adapted for small bore holes. It is highly suitable for adoption in cases like that at Tunbridge Wells, where there is an existing pumping station at a considerable distance from the well, and from which the lift can be operated. The aeration of

TESTS OF AIR LIFTS.

Place.	Depth of Immersion of Air Pipe in Feet.	Height of Delivery in Feet.	Ratio of Immersion to Lift.	Diameter of Rising Main (Inches).	Diameter of Air Pipe (Inches).	Quantity of Water Raised (Gallons per Hour).	Quantity of Air at Atmospheric Pressure (Cub. Ft. per Minute).	IHP. of Air Cylinder.	Cubic Feet of Air required at Atmospheric Pressure per Gallon of Water.
Sugar Factory at Glogan	95	42·75	2·22	$6\frac{1}{2}$	3	27,700	215	27·47	·465
	93	45	2·07	$6\frac{1}{2}$	3	37,000	280	35·12	·454
	95	42·75	2·22	$6\frac{1}{2}$	3	39,600	328	42·54	·51
	95	42·75	2·22	$6\frac{1}{2}$	3	40,000	425	59·16	·654
Yard Works, Zwickau	63·25	45	1·4	$7\frac{9}{16}$	$4\frac{15}{16}$	53,700	348	42	·389
Brostowe Estate, near Friedheim	301	203	1·48	2	1	2,190	28	10·52	·766
Solvay Works, Saaralben	403	229	1·76	$2\frac{7}{16}$	$1\frac{3}{8}$	2,870	44·7	19·4	·938

The proportions between the diameters of the delivery and air pipes are not of an exact character. Mr Maxwell considers that the velocity of the air should not exceed 20 feet per second. At Tunbridge Wells, in a delivery pipe 7 inches diameter, the air pipe is $2\frac{1}{2}$ diameter.

Mr Maxwell's formulæ for calculating the quantity of air to lift a given volume of water to any specified height is—

the water, especially when it contains iron, is also a point in favour of the system.

Air,—Liquid.—*See* **Liquid Air.**

Air Lock.—*See* **Caisson.**

Air Locomotive.—*See* **Compressed Air Locomotive.**

Air Meter, or Anemometer.—An instrument for measuring the velocity of the air in blast mains, and pipes, and mines. It comprises a small fan, the rotation of which imparts movement to counters and dials on which the rate of velocity is indicated.

Air Motor.—*See* **Air Engine.**

Air Port.—*See* **Gas Furnaces.**

Air Pump.—If it were not that water contains a considerable volume of air and other gases in solution, and that air leaks into a vacuous space through bad places in castings and imperfectly packed glands, it would be possible to work a condensing engine with a closed condenser supplied with a jet of cold water and with a discharge pipe carried down 34 feet to a pond below the water surface of which the pipe would extend to seal out the entrance of air. But it is not practically possible to achieve the exclusion of air, and it was for this reason that when Watt invented the separate condenser he had to provide an air pump to remove such inleaking air. From that time a steam-engine condensing plant has included an air pump of some form, the duty of which is to remove the air which would ultimately collect in the condenser and entirely neutralise its effect.

In the absence of air, the pressure in a condenser is that of water vapour at the temperature at which the condenser stands at the moment. Thus if the condenser temperature is 100 degrees Fahr. the pressure of water vapour at this temperature is 0·944 of 1 lb. or 28 inches below atmospheric pressure. The normal atmospheric pressure being 14·700 lb., the "vacuum" corresponding with a condenser temperature of 100 degrees Fahr. will be $14{\cdot}700 - 0{\cdot}944 = 13{\cdot}756$ lb. or 28 inches.

If, however, for each 14·7 cubic feet of condenser space there be admitted 1 cubic foot of air, the pressure of this air at that degree of expansion will be $\frac{1}{14{\cdot}7}$ of $14{\cdot}7$ lb. $= 1$ lb. per square inch.

The law of mixed vapours teaches us that when two independent gases occupy the same space, the pressure in that space will be the sum of the pressures that would be exerted by each gas if it occupied that space alone. It is also a law that if water at any given temperature occupy a given vessel, the space not occupied by the water must be occupied by its vapour, and each cubic foot of the space will contain a fixed weight of water vapour proper to the temperature of the water. This is necessary by the law of molecular equilibrium (Dalton), and it holds good irrespective of what other gas be present with the water vapour. Obviously, therefore, if water vapour separately exerts a pressure of 0·944 lb. at a given temperature, the presence of air, by itself capable of creating a pressure of 1 lb., will combine to produce a joint pressure of $1{\cdot}0 + 0{\cdot}944 = 1{\cdot}944$ lb. Thus the vacuum gauge on a condenser always reads less "vacuum" or higher pressure than that proper to the temperature, and the cause of the discrepancy is air. When this air is withdrawn by a pump, the pump takes into itself the mixture of air and water vapour. As the bucket moves and contracts the occupied space, some of the water vapour condenses, and the rise of pressure in the enclosed space is simply that due to the air as it is compressed; so far as regards the water vapour, its pressure does not vary, but remains at the pressure proper to the temperature.

In air pumps with solid buckets the bucket descends away from the discharge valve and creates above itself a vacuum free from air, and of a pressure which corresponds with that due to the water sealing on the bucket. When communication is then made with the condenser the mixed vapour in this at a higher pressure rushes into the air pump, and in this way the air pump at each stroke gets hold of a certain volume of mixed vapour, part of which is air, and is enabled to discharge the air on the next up stroke into the atmosphere. In air pumps of the type which have a valve in the bucket, the descending bucket also would leave an empty space above itself, but that its valves open, and the space above the bucket fills with mixed vapour from the condenser at the condenser pressure. In this case, therefore, the bucket at each stroke draws out the maximum amount of

air that can be drawn out, and this type of pump is still preferred by some engineers, while others prefer those with solid buckets generally known as the Edwards' type.

A third form of pump is that known as the ejector condenser. In this variety steam is condensed in a moving jet of water, and the velocity of the steam combines with that of the water to produce a velocity of the combined jet which is $\frac{V \times m + v \times M}{m + M}$ where V and v are the velocities of the steam and of the water, and m and M their mass respectively. The action of an injector condenser is exactly that of the feed injector, and a vacuum as high as 12 lb. can regularly be obtained by their means. Another air pump is known as the dry air pump, and it is attached to the head of the barometric condenser first named, and serves to withdraw the air which alone prevents a 34 feet drop pipe from giving the highest vacuum that it is possible to attain from that device. If the velocity of the exhaust steam be taken at 888 feet per second, and the water approaches at a velocity of 30 feet per second, and is of 29 times the weight of the steam, then by the above formula we have the velocity of the combined jet as follows:—

$$\frac{888 \times 1 + (30 \times 29)}{1 + 29} = \frac{1758}{30} = \text{nearly 60 ft. per sec.}$$

A velocity V of 60 feet per second is that due to a head of h where $V = 8\sqrt{h}$, whence $\sqrt{h} = 7\frac{1}{2}$, and $h = 56$ feet or 24 lb. Thus if of perfect efficiency an ejector condenser should give the highest possible vacuum consistent with the temperature, and actually vacuo of over 13 lb. have been obtained with it. This example serves to show the great importance of some velocity of approach of the water jet. In the present case it nearly doubles the value of the numerator. Had the mean jet velocity been 32 feet per second only, representing a head of 16 feet of water, the vacuum could not have reached even 7 lb., though with cold water and a ratio of water to steam of 21 only, the velocity of the final jet would have been 40, and the equivalent vacuum nearly 11 lb., but even this shows the advantage of initial water jet velocity.

Though vertical pumps are more usually employed, those of horizontal type are sufficiently common to be well known. In the manufacturing districts of Lancashire and Yorkshire horizontal air pumps have been often employed in order that they might be worked directly off the rear extension of the engine piston rod, and thereby avoid the complication of links, crosshead, and angle lever necessary where a vertical pump must be driven by a horizontal engine.

Some forms of horizontal air pumps have a horizontally moving bucket or displacement plunger, and these move in solid water, the surface of which, in end chambers of some height extended beyond and above the level of the pump barrel, rises and falls vertically in obedience to the movement of the bucket, and becomes itself the real acting surface of the pump, pushing above it any air through the delivery valve, and itself passing through the valve to the extent necessitated by the influx of condensed steam, or in case of jet condensers of the water of condensation from the condenser. It is obvious that in this form of pump a difficulty may arise in consequence of the high speed of the bucket. The water should be able to follow the bucket at the maximum velocity of this without cavitation. There is no air pressure above the water surface to push down the water and compel this to follow the bucket. Pressure of the water itself can alone be relied upon, and such pumps, when properly constructed, must have end chambers sufficiently large to reduce the rise and fall of the water surface to reasonable velocities and extent by giving the end chambers a cross-sectional area sufficiently greater than the barrel area to effect such reduction. Then the height of the water level above the pump centre must be such that the pressure due to the height shall be sufficient to give the necessary velocity of flow to the water to enable it to follow up the bucket closely. Thus a bucket moves 10 feet per second average velocity, or say 16 feet as maximum velocity at or near mid stroke. In getting up this velocity in a course of say 2 feet, it has occupied at, say 90 revolutions per minute, $\frac{1}{6}$th second.

In $\frac{1}{6}$th of a second, gravity gives a velocity

acceleration of 5 feet. Obviously the effect of gravity must be increased by pressure from above. The velocity of outflow of water under pressure of a given head is $V = \sqrt{2gh}$ where V = velocity in feet per second, $g = 32 \cdot 2$ = gravity, h = head in feet. Now we have V = 16 feet as one item given. Hence $16 = 8\sqrt{h}$, and $\sqrt{h}$ will be therefore $= 2$, and $h = 4$ feet, and this would require to be the height of the water surface in the end chambers in order to force the water to follow close to the bucket, and so enable the pump to run without shock or water impact.

$=\frac{16}{64}=\frac{1}{4}$ foot. In this case the bucket would fall freely 3 inches by gravity where it is driven down 4 inches, and any water upon it would lag behind the bucket 1 inch. In such pumps it is therefore the case that above a certain speed the uprising bucket simply meets a quantity of broken water which is spread evenly on the bucket. Some is discharged with the air, the rest is left behind by the more rapidly descending bucket, and churned up by the next incoming spray dashed in by the descending bucket round the curved passages at the base, as seen in Fig. 31, which represents an Edwards' type air pump

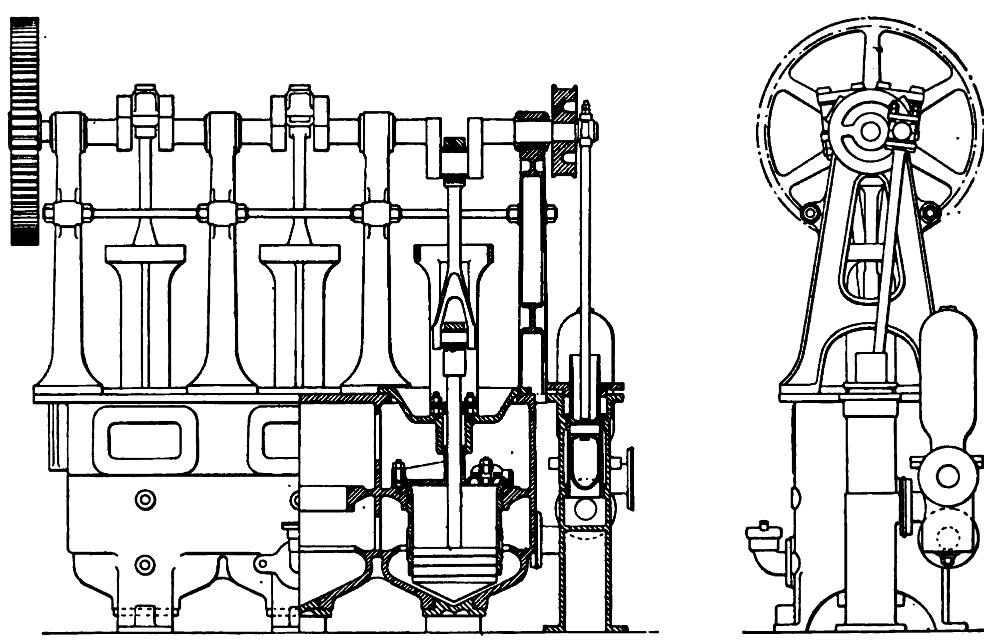


Fig. 31.—Edwards' Triple Barrel Air Pump.

No such calculations are necessary with vertical pumps which simply deliver all the surplus which comes into them, but it is instructive to calculate from the velocity of high-speed air pumps of the solid type just what happens to the sealing water imprisoned within them. It will be found that the bucket velocity is often greater than gravity. Thus let a pump at 240 revolutions per minute be taken with a stroke of 4 inches. The mean duration of one pump stroke is $\frac{1}{8}$ second. In this time by the law of falling bodies, which gives the distance fallen through $= s = 16t^2$, we have $t=\frac{1}{8} \therefore t^2=\frac{1}{64}$ and s

made by Messrs W. H. Allen, Son, & Co., Ltd., of Bedford. Obviously speeds and the influence and effects of gravity must be carefully considered in air-pump design, for it will not be safe for a high-speed bucket to meet solid water, though no harm can come from collision with a shattered mass of air-cushioned spray.

As with steam engines and air compressors, so also air pumps may be worked in two stages, if thought necessary. Two examples only need be cited, the one that of the Parsons steam jet vacuum augmenter, which induces a flow of air from a condenser at say 28 inches "vacuum,"

and raises its pressure to 26 or 26½ inches, at which the air pump proper takes hold of it. The steam jet and the air it draws with it pass through a supplementary condenser about $\frac{1}{20}$ the surface of the main condenser, and as the air is increased several times in density the capacity of the final air pump to remove air is rendered so many times greater than if it were not fed with densified air.

A second example of stage air-pump working is the use in the Manhattan Power Station of New York of a modified Beales rotatory gas exhauster as a dry air pump to compress the air from the head of a barometric jet condenser, and to deliver it to the barometric column at a lower point whence it is easily swept away by the descending column. If stage working of air pumps should be thought worth the capital expenditure, the probability is that the first pump might well be of some such rotatory type, the final pump being of the bucket variety and probably somewhat smaller than customary. In most cases it seems probable that the attention to be given to the extra machinery, if expended on existing plant in securing air tightness, would pay as well, apart from the saving in capital.

Types of Air Pumps.

The Edwards' Air Pump.—The Edwards' air pump, Fig. 31, is one of the modern developments of air-pump practice, and is of that variety which has solid or valveless buckets, and it also dispenses with the foot valve. It is run at a high rate of speed, and this has enabled it to be driven by an electric motor with single reduction gearing. Another peculiarity of the Edwards' pump is the conical form of the lower face of the bucket or plunger, and of the lower part of the barrel in which it works. The barrel or casing floor is below the condenser, and water flows into it from the condenser. Curved passages extend round the lower part of the barrel, and these are so directed that when the conical bucket strikes quickly upon the collected water, this is shot violently round the curved passage, and enters the air-pump barrel above the bucket which has just uncovered a ring of ports through the barrel a fraction of a second before striking the water below it.

Thus the uncovering of the ring of ports leaves an opening through which rush vapour and air, and the water shot up from below. The water, as may be seen in a glass model, shoots high up the barrel, and before it settles again, the bucket has already risen and closed the ports, and when the bucket reaches the top of its stroke the imprisoned and now compressed air is forced out through the top valves followed by any excess of water above what is necessary to fill the clearance space between bucket and outlet valve. On the descent of the bucket a vacuum is, as already explained, formed above it as perfect as the temperature of the water will permit, and when the bucket opens the lower ports this vacuum is at once brought up to mean condenser pressure by the inrush from the condenser, which can only be such as to occupy a part of the pump volume, as already explained. The following table shows the results obtained with certain condensers and the Edwards' air pump, and it is

Type of Condenser.	Revolutions per Minute.	Vacuum in Inches.	Barometer in Inches.	Temperature of Air Pump Discharge, Fahr.	Pressure due to Temperature.	Difference between Vacuum obtained and Vacuum possible had no Air been present.
No. 1 Surface	240	30·2	30·85	65°	0·619	0·03
	250	29·6	30·80	83°	1·100	0·10
No. 2 Surface	375	28	30·45	107°	2·369	0·081
No. 3 Jet	128	28·25	30	88°	1·328	0·422
	128	28·375	30	84°	1·169	0·456

useful in showing something of what may be expected from different condensers, the jet condenser bringing in so much more air than the surface condenser, and making the difference in the last column so very much larger. An effort is required to drive down the bucket of these pumps against the higher pressure in the condenser, and, on the up stroke, while the bucket commences in equilibrio, the pressure on its upper face increases as the air is compressed into smaller space.

The Edwards pump is driven either by connecting its bucket rods with the piston rod of a steam cylinder placed vertically above, or it may be driven by an electric motor through single reduction gear of no serious reduction ratio. Fig. 31 is a treble barrel pump as made by Messrs Allen, with buckets 11 inches diameter × 8 inches stroke, and driven by gearing from an electric motor.

A three-barrel pump with 14-inch barrels and a stroke of 12 inches will deal with 45,000 lb. of condensed steam per hour from a surface condenser when run at a speed of 150 revolutions

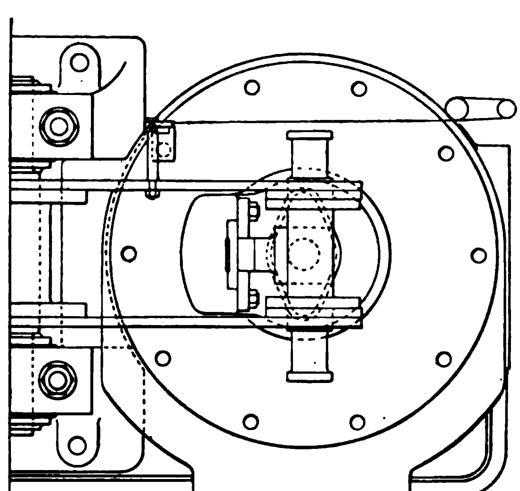


Fig. 32.—Air Pump. Davey, Paxman, & Co., Ltd., Colchester. (End View.)

per minute. This represents about 1,150 cubic inches of volume per pound of feed water, calculated on one working stroke of each barrel per revolution. When driven by gearing, this should be broad on the face, of reasonably fine pitch, and machine cut. The pinion may be of raw hide and the length of the teeth should not exceed half the pitch.

Double-acting Air Pump.—In order to reduce the dimensions of an air pump to a minimum it may be made double-acting. This necessitates again a solid bucket. Figs. 32, 33 show

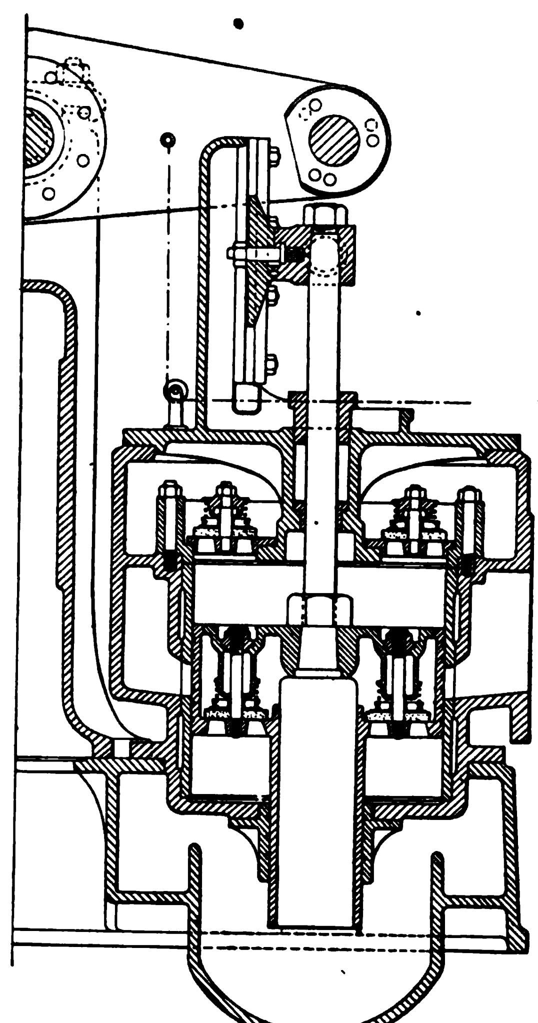


Fig. 33.—Air Pump. Davey, Paxman, & Co., Ltd., Colchester. (Sectional Elevation.)

a double-acting pump, which explains how the problem has been solved by Messrs Davey, Paxman, & Co. There is a ring of ports round the middle length of the barrel, and these are uncovered by the bucket at the end of each stroke, and admit water and mixed

vapour from the condenser. What water runs in upon the upper face of the bucket is discharged through the top delivery valves, and, apart from the method of water entry, the bucket action in no way differs from that of the Edwards' pump. The water and air which enter below the bucket are discharged into the bucket, which is hollow, and away by a central trunk which works in a shell, water-sealed to prevent reflux of air. The special pump illustrated is designed for driving marine-fashion, by a lever from the crosshead of an engine. Such a pump, 14 inches diameter × 7 inches stroke, will run at 250 revolutions per minute, or 500 strokes. The flow of water through the ports is hastened by the excess of vapour pressure in the condenser above that in the air pump.

Displacement Air Pump.—At Fig. 34 is seen an example of the displacement type of air pump as made by Messrs Hick, Hargreaves, & Co. for large factory engines. The bucket is simply a spherical-ended plunger working in a cylindrical shell placed between an upper and lower chamber. The pump casing is full of water, and pumping takes place by the displacement action of the plunger. When it recedes from one chamber, the inlet valves open, and admit water and vapour, while at the same time the volume of the other chamber being reduced, air and water are expelled. The sloping upper boundary of each chamber is a lesson in air-pump construction, for it shows that attention has been given by the designer to the escape of the air, and it will be noticed that the outlet valves open out flush with the top of the chamber, so that no pocket of air can form to vitiate the action of the pump. This is a type of pump suitable perhaps more specially for large engines.

The Direct-driven Air Pump.—The horizontal air pump direct driven by a steam cylinder, and often connected in tandem with a circulating pump, is frequently placed below a surface condenser to form a combined condensing set. These pumps resemble the duplex water pump, and are usually fitted with inlet and outlet valves of indiarubber.

This style of condensing plant is rather characteristic of American than of English practice.

Such pumps are run at slow speeds, whereas English air-pump practice has tended for some years towards considerable speeds of rotation.

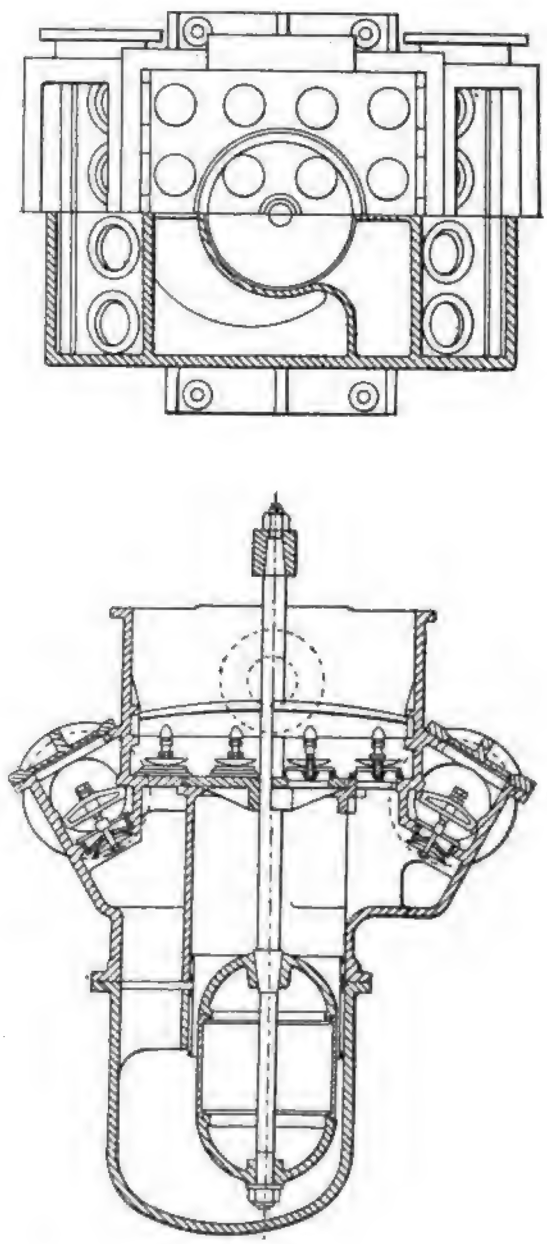


Fig. 34.—Displacement Air Pump for Large Engines. Hick, Hargreaves, & Co., Ltd.

In the tail rod pump of Pollitt & Wigzell, Fig. 35, the air-pump stroke is as long as that

of the steam piston, which may be 5 feet. The pump barrel stands out horizontally in the base of the condenser, and is open all round. A series of slots through the pump barrel are uncovered by the bucket on its outward stroke, and the inrush of air and vapour into the better vacuum carries in water also. The imprisoned mixture is forced out, by the return

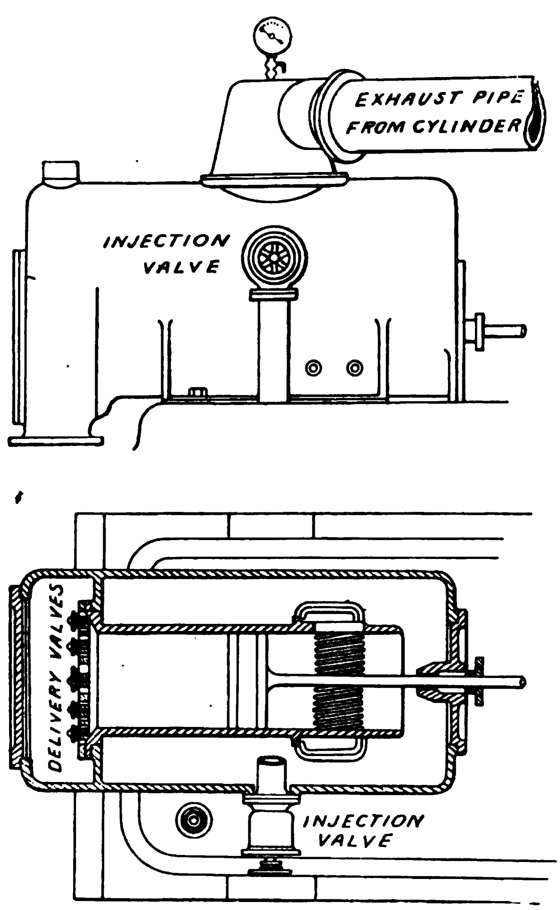


Fig. 35.—Tail Rod Pump. Pollitt & Wigzell, Ltd.

of the bucket, through valves at the end of the pump barrel, and owing to the velocity of the bucket it is probable that the air is all in front of the water, and that the water is flatly spread over the advancing face of the bucket. This bucket never works in solid water, and could always remove more water per stroke than what it gets, so that the water level in the base of the condenser is always kept down to a minimum height. This pump is fitted to surface condensers as well as to the jet condenser shown in Fig. 35.

There is no fixed practice as to air-pump design or the method of driving. In marine practice the air pumps, except perhaps in the larger ships, are driven from the main engine by a long and short-ended lever pivoted on the back frames of the engine. In old-fashioned land beam engines the pump is worked from the back gudgeon of the parallel motion. In horizontal engines it is driven by a tail rod as in Fig. 35, or if wanted to be of vertical type, the pump is placed in the basement below, and behind the engine and driven off the tail rod of the back cylinder through an L lever. This L lever has also been employed connected by short links to the main crosshead, the pump being nearly under the cylinder.

An occasional method of driving is by a connecting rod from the extension of the crank pin, the pump being vertical and beneath the floor level.

Large eccentrics have been used to drive air pumps, especially in small vertical engines with the cylinder below the crank shaft. The introduction of high-speed engines led up to the independently driven air pump, it being assumed that air pumps could not be run fast. But as seen above, air pumps have been made to run as fast as engines, and with the growth in the power of large electric-light engines we now find engines are running slowly once more in numerous cases, but the high-speed air pump remains as a legacy of the high-speed fashion. The essential things to remember are those first principles, without which no pump can be a success.

It is obvious that a fast-running pump dealing with water may be run so quickly that the amount of water to be dealt with per stroke will be so small as not to cause serious shock. This is the principle of the Edwards' pump.

Another important point in design is so to arrange the air pump that all air will be promptly discharged from the barrel. Otherwise the presence of air will vitiate the action of the bucket in producing a vacuum above it. Given attention to such details, there should be very little difference between the performance

of one well-made and well-designed air pump and another.

With regard to the question of condensation at high altitudes, since up to 6,000 feet above sea level a vacuum is possible of over 12 lb., or higher than much careless practice secures near the sea level, the subject need not be very seriously considered. At lower atmospheric pressure less air dissolves in feed water, leakage is reduced, and less work is required to drive an air pump. Those small gains make up something of what the engine fails to gain by higher vacuum.

Air Receiver.—A cylindrical vessel of steel plate, riveted with ends similarly to the shell of a vertical boiler, and into which the air under pressure is discharged from the air compressor. It is fitted with a safety valve and pressure gauge, and blows off when the maximum working pressure is exceeded. Its capacity is estimated in cubic feet of *free air* per minute.

The air receiver does not, like a steam boiler, contain a large storage of power. Its function is more that of an equaliser of pressure, resembling in this sense the function of an air vessel. The compressor delivers air in a series of pulsations, the receiver equalises these, and delivers a steady pressure of air to the machinery. The best location for a receiver is about 50 feet away from the compressor. The receiver also arrests the slight amount of water which accumulates, and is provided with drawcocks for its removal.

Receivers are either vertical or horizontal, to suit requirements. A manhole is provided, and flanges for inlet and discharge pipes. As receivers have to stand pressures equal to, or exceeding those of steam boilers, they are constructed with similar regard to strength, and are also tested considerably above the working pressures.

Air Reheater.—A form of stove used for reheating air that has been deprived of much of its heat in its passage through the air cylinder of an air compressor. It has been found that if the heat lost during compression is restored before use, a gain in efficiency is obtained. If air is raised to a temperature of 360 degrees Fahr., a gain of 35 per cent. is obtained, by comparison with the same volume of air used cold. It is important that the heater be placed as near as possible to the location where the heat is to be used, and that the outlet pipe should be short, and clothed to prevent radiation and loss of heat.

Air Resistance.—The air resistance of trains is a subject for which no simple formula covers all the facts. Roughly, it is accepted as a working theory that the atmospheric resistance varies nearly as the square of the velocity, and as the surface exposed, and that the latter is nearly proportional to the weight of the train. The atmospheric resistance is proportionately less for a long train than a short one. It has also been held that the resistance is less for high speeds than for low, on the ground that at high speeds the train carries a moving mass of air with it, the friction of which against the still atmosphere is less than that of the angular surfaces of the train. But the old experiments were only conducted at moderate speeds—under 50 miles an hour. At present when velocities of 120 miles have been reached with electric train experiments, the old views seem to be inapplicable.

Devices have been proposed for lessening the effects of air resistance to trains. Many French locos are provided with plows.

Air Resistance in Fly-wheels.—It has been generally accepted that the air enclosed between the arms of fly-wheels revolves with the wheels, and thus offers little resistance to their revolution. Experiments have not borne out this assumption. At one of the electric power stations of Nürnburg (Germany) two tandem compound engines of 450 HP. each, connected direct to generators and running at 95 revolutions per minute, were tested as follows:—The fly-wheels had arms of channel section, and the engines were tried first with the arms bare, and then encased with sheet iron. Without the casing there was a motor consumption of 13,300 watts, but with the covering in place only about 9,000 watts. The saving due to the casing was 3,400 watts, or about 5$\frac{3}{4}$ HP. Professor C. H. Benjamin also made some experiments in America in connection with the speeding up of small fly-wheels to the bursting point. With some wheels with transverse flanges in and near the rim it was found impossible to attain

a speed beyond 3,000 revolutions per minute. Then the arms were closed with discs of sheet iron, and the bursting speed was reached in two minutes. In the case of a 24-inch wheel without the sheet casing about 10 HP. was absorbed at the maximum speed attainable.

Air Ships.—*See* **Flying Machines.**

Air Thermometer.—Santorio, a physician of Padua, is credited with the invention of the air thermometer in 1590. Thus in point of age it takes precedence of both the mercury and the alcohol thermometer, and is still unsurpassed for delicacy of measurement—the coefficient of expansion of a gas being greater than that of liquids—and for recording very low temperatures. It is, however, open to the great objection that a correction has to be made for the pressure of the atmosphere every time an observation is made. This is owing to the fact that the volume of any gas varies, (inversely), as the pressure. But the pressure of the atmosphere continually varies, a fact which renders the air thermometer a difficult instrument to read. The absolute zero of the air thermometer is -273° Cent. Since a gas expands $\frac{1}{273}$ of its volume when heated through 1 degree, or loses $\frac{1}{273}$ of its volume when cooled through 1 degree, it follows that if the air were cooled to -273 degrees it would theoretically cease to exist, having lost its entire volume. Hence this number is taken as the absolute zero, and temperatures measured from this zero are called absolute temperatures.

Leslie's differential thermometer is a type of air thermometer. It consists of two air bulbs which are connected by a bent glass tube containing a quantity of coloured sulphuric acid. If one of the bulbs be heated, the air it contains will be expanded, thus moving the index of coloured acid. This thermometer does not therefore indicate actual temperature, but only differences of temperature, and is naturally a very delicate instrument.

Air Valve.—Any valve through which air escapes from, or is admitted to compressing, and pneumatic machines and appliances.

Air Vessel.—The function of an air vessel is to equalise the variations in the flow and pressure of water which is being delivered by pumps through long delivery pipes. The explanation of the action of the air vessel is that motion is imparted to the water in the rising main by the forward stroke of the pump piston, but during the backward stroke the water is at rest. Hence the movement of the water is not continuous, and the pump has to overcome the inertia of the water on its forward stroke. The expansion of the compressed air in the upper part of the vessel, which takes place during the backward stroke, exercises pressure on the water in the pipe, and so keeps it in motion during the backward stroke. Its position is near the pumps, and on top of the rising main, being bolted to one of the pipes by means of a flanged branch, or it may be located upon the pump body. The foregoing also explains why an air vessel is not necessary when pumps are double-acting, or in the case of three-throw pumps. The longer the pipes, and the lower the pressures, the larger should be the capacity of the air vessel. Air is simply stored in the vessel under the pressure of the liquid. As some of the air is always being absorbed by the water, the supply would lessen if the capacity of the vessel were not made large enough to hold a sufficient supply to compensate for this. On the other hand, some amount of air is always present in the water being pumped. Under ordinary atmospheric pressure, water absorbs 0·046 of its own volume of oxygen, and 0·025 of nitrogen. The capacity of air vessels varies from two to six times the capacity of the pumps, or more according to pressure, and length of delivery pipes.

Alarm Check Valve.—*See* **Check Valve.**

Alarm, Electrical. — *See* **Electrical Alarm.**

Alarm, Low Water.—*See* **Low Water Alarm.**

Alcohol.—It is to the potato spirit, in the distillation of which Germany stands pre-eminent, that this article relates. The utilities of cheap alcohol are not recognised nearly so much as they should be in Britain. In Germany, the industry, and those which depend upon it for cheap power, are fostered by the paternal Government. Latterly a new interest has been taken in the subject by reason of its rivalry to petrol, alcohol being free from many of the objectionable features of the latter.

The origin of the German alcohol industry is traceable to the prescience of the officials of the War Department, who pointed out that kerosene and gasoline engines could only be operated by one or other of the products of imported petroleum, the supply of which in case of war might be cut off. But the sandy soil of large tracts of Germany is eminently suitable to the culture of potatoes, from which alcohol can be easily manufactured. Also, the crude molasses left from the beet sugar manufacture, and which cannot be crystallised, can be utilised in the production of alcohol.

Objection is made to the use of alcohol for motors on the ground that it possesses a lower heat of combustion than most other fuels. By comparison with petrol, which comes chiefly into rivalry with it, it has only half the value of that oil, alcohol being taken at 5,500, and petrol at about 10,250. But other matters enter into the calculation, chief among which is the relative cost of the different fuels. As things are in England at present, alcohol cannot possibly compete with petrol, while in Germany its consumption increases. In 1900-1 Germany produced 406 million litres of alcohol, of which 112 millions were consumed for technical purposes. During the previous six years it had grown from 71 million litres used for technical purposes. In 1900-1 the consumption in this country for the same purposes was only 13 million litres! During the six years previous, our consumption has grown from 9 millions only.

The vast difference must be regarded as being entirely due to the fostering care of the German Government. Concessions were granted for duty-free alcohol to many industries, and the cultivation of potatoes was encouraged, and also the establishment of distilleries in the midst of the potato-growing districts. In 1887, when legislation was first brought to bear on the subject, commercial alcohol cost, retail, from 3s. 6d. to 4s. per gallon. Now it can be obtained at from 1s. 3d. to 1s. 4½d. per gallon in stoppered bottles. The result is that an important home industry is fostered, the great public bodies as well as private individuals use it for power, light, and manufacture, and the trade in dyes, drugs, and artificial perfumes, who use alcohol, is rapidly ousting our own. Alcohol, moreover, is free from the disagreeable fumes given off from petrol and paraffin, and is therefore more desirable as a source of power than these. It might also be manufactured largely here, and so render us independent of outside supplies, an important consideration in time of war. If it were cheap, its low efficiency would be discounted at once.

But its heat of combustion is not so poor as it appears at first sight. In Germany, and France, where alcohol is used extensively for motors, the efficiency has been raised by increasing the compression, and by raising the temperature of the water in the cooling jacket of the cylinder. In 1902, in a competition fostered by the German Agricultural Society, ten alcohol-driven gas engines gave efficiencies of from 32·7 to 30·9 per cent. when working on full load. These remarkable results are obtained in some cases with a compression up to 10½ atmospheres. The greatest explosion pressure attained was in a number of cases as high as 33 atmospheres. It is necessary to raise the temperature of the water in the cooling jacket, in order to prevent the condensation of the air saturated with alcohol and water. The amount of alcohol required in some cases to drive a motor on half load was found by Fehrmann to be 100 per cent. more when the water in the cooling jacket was kept at about 15° Cent., than when it was at 100° Cent. It is further found that a carburetter which delivers the mixed air and alcohol vapour at a temperature as little as possible above that necessary to retain the alcohol in the form of vapour gives the most economical results. The employment of alcohol under these circumstances is in a fair way of extension, taking the place of petrol motors. But little has been done as yet in this country in the matter.

Alder (*Alnus glutinosa;* Lat. *alnus;* Celt. *al*, near, and *lar*, the edge of a river; sp. gr., 0·56; weight of a cubic foot, 35 lb.).—A soft, light wood, allied to birch in character. It thrives best in extremely moist situations. After it is cut it is more durable in water than in air. It was used for the piles of the Rialto, in Venice. But it lasts longer if absolutely dry than if alternately wet and dry. Its colour is reddish-yellow in different shades. It is

valuable for under-water purposes, such as piles, sluices, &c. It is used for bobbins, clogs, pattens, French sabots, basins, plates, herring barrel staves. Dyes are obtained from the bark and shoots. The bark is bitter and astringent. Alder is largely used for making charcoal for gunpowder. It is uniform in texture, soft, and easy to work, but shrinks rather badly. In Britain it is very common, but does not attain a large size, seldom exceeding 40 feet in height. In large quantities it is obtained chiefly from the large alder swamps in Western Russia and Eastern Prussia.

Algebraical Signs.—The common signs used in algebraical expressions and processes are as follows:—$+$ (plus) denotes that the quantities between which it is placed are to be added together; $-$ (minus) that the quantity before which it is placed is to be subtracted from the one preceding it; the sign $=$ signifies that the numbers between which it is placed are equal. Thus $a+b+c=d$ means that the sum of a, b, and c is equal to d. $\times$ denotes that one number is to be multiplied by another. This sign is frequently omitted, thus abc has the same meaning as $a \times b \times c$. The sign $\div$ means that the quantity which precedes it is to be divided by the one which follows it. Here again we have an alternative way of expressing division, one number being placed over another as in vulgar fractions; $\frac{a}{b}$ therefore signifies the same as $a \div b$, namely, that the quantity represented by a is to be divided by the quantity represented by b. The signs $<$ $>$ are read respectively as "is less than" and "is greater than." $a<b$ means a is less than b; $a>b$ means a is greater than b, the opening of the angle being turned towards the larger quantity. $\therefore$ denotes "therefore" and $\because$ "because."

The sign $\sqrt{}$ placed over any quantity signifies that its root is to be extracted, the particular root being indicated by a small figure placed above this sign. Thus $\sqrt[3]{b}$, $\sqrt[4]{b}$, $\sqrt[5]{b}$ are read respectively as the third, fourth, and fifth roots of b. In the ease of the square root, however, the figure 2 is usually omitted, so that $\sqrt{9}$ is understood to mean the square root of 9.

When a number is multiplied by itself a number of times, as for instance, $b \times b \times b \times b$, this is denoted by b^4. So that if we wished to multiply a by itself twice, b by itself three times, and c by itself four times, and to express the product of all these quantities, it would not be stated as $aabbbcccc$, but as $a^2\,b^3\,c^4$, and read as "the product of a squared, b cubed, and c to the fourth power."

Brackets are extensively used in algebra. To prevent confusion, pairs of brackets of different shapes are used, as (), { }, [], while a long stroke, ——, called a vinculum, sometimes occurs. Two very important rules must be observed in using brackets:—(1.) When a bracket is preceded by the sign $+$ the bracket may be removed without altering the signs of the terms in it. (2.) When a bracket is preceded by the sign $-$ the sign of each term contained within the brackets must be changed.

In cases where several brackets are used it is usual to commence by removing the innermost pair. Thus:—

$$a-[b-\{c-d-(e-f)\}]=$$
$$a-[b-\{c-d-e+f\}]=$$
$$a-[b-c+d+e-f]=$$
$$a-b+c-d-e+f$$

Alignment.—Parts of machinery which are in line with each other are in alignment. The head and tail centres of a lathe, for instance, or a length of shafting and its bearings, are in alignment. The term also denotes the act of adjusting to a line.

The methods by which alignment is secured in shop practice vary with the nature of the work, and the degree of accuracy desired. In general, alignment is checked in one of two ways, either by reference to a surface known to be horizontal, or by means of a spirit level. In the first case the surface may be a level one, on which the parts to be aligned rest, or a portion of the work itself is levelled, and used as a base from which to operate. The second depends for its truth on the accuracy of the spirit level, or on the method of its manipulation, as turning it about end for end if not quite true, or else the level is used as a check upon, or in combination with other devices. The common rule alone plays but a small part in aligning work, except by affording rough approximations. In the finest work devices are adopted for multi-

plying minute errors, as in the high-class **Indicators**.

The alignment of shafts and of centres affords the most common examples. The preliminary work of marking out for boring holes is done when possible on the marking-off table, using a surface gauge, which ensures the centres so marked at one setting being at the same height. After the holes are bored, and the shafts are in place, the surface gauge is again used, checking the top and bottom of the shafts. The centres of lathes are checked in similar fashion from the surface of the bed; but if very fine precision is required, an indicator is used, by which any error is multiplied a hundredfold. In the case of work for which no level base can be found, as in heavy cheeks, or bedplates that are erected on wood blocking, the main casting or castings are levelled up on wood blocking until some faced or bored part or parts are got true by the level. In the case of holes in frames, set at some distance asunder, and bolted together, a shaft is inserted in the holes, and its top tested with a spirit level. Then when facings or shaft holes are thus levelled, all other shafts, facings, and horizontal faces can be tested either for alignment or parallelism by spirit level.

The case of shafting stands apart, and will be more suitably treated *in extenso* under the head of **Shafting**, because there are several methods by which shaft bearings are aligned.

Alignment of large erections is done by means of straining a fine wire or cord between parts. The "set" of beams under strain is often tested in this manner. A more correct method is that of the theodolite, which alone is suitable for checking objects that are at a considerable distance apart. Alignment in a perpendicular direction is done by plumb lines, or plumb rules, and spirit level in combination.

Aliquot Part.—One number is said to be an aliquot part of another when it divides evenly into that number without leaving a remainder. Thus, 5 is an aliquot part of 100 because it is contained exactly 20 times in 100. Similarly 6d. is an aliquot part of 1s.; 4 stones is an aliquot part of a hundredweight; 9 inches an aliquot part of a yard; and 12 hours an aliquot part of a day. The arithmetical rule of Practice is a method of finding the value of any number of articles by means of aliquot parts.

All-gear Head.—A term applied to the fast headstock of those lathes in which stepped cones are abandoned for a single belt pulley, and toothed gears for changing speeds. *See* **High-Speed Lathes.**

Alligator Shears.—*See* **Shears, Shearing Machines**.

Allotropy.—The property possessed by some elements and compounds of existing in more than one form so far as their physical properties are concerned. The diamond, the graphite in a lead pencil, and a lump of charcoal are widely different in their appearance and physical properties, yet chemically they are perfectly identical with each other, each one consisting of carbon. Hence we speak of these three varieties of carbon as allotropic modifications of the element.

Sulphur too occurs in several allotropic modifications differing in crystalline form, in colour, and solubility in carbon bisulphide. It is found in octahedral crystals readily soluble in CS_2; in crystals of prismatic form from fusions; and in the peculiar plastic form, obtained by heating sulphur to about 230° Cent., and pouring it into cold water, where it settles as a soft tenacious mass readily drawn out into long threads. In the latter form it is insoluble in CS_2. Unlike the allotropic modifications of carbon, these forms of sulphur change more or less rapidly into ordinary sulphur.

Phosphorus again occurs in various allotropic forms. First we have ordinary phosphorus, kept under water on account of its great inflammability when exposed to the air. If ordinary phosphorus is heated to a temperature not exceeding 240° Cent. in an atmosphere incapable of acting chemically upon it, it becomes changed into a red amorphous condition. This form is non-poisonous, and need not be kept under water. It may even be heated up to 250° without igniting. Above that temperature it is changed into ordinary yellow phosphorus, inflames, and is transformed into the pentoxide. The paper on the side of a box of safety matches is coated with a mixture of amorphous phosphorus and powdered glass.

In the atmosphere there exists a very

interesting example of allotropy, for oxygen and ozone are allotropic forms of the same gas. Ozone is really condensed oxygen possessing 1½ times the density of the latter. Ozone is formed, among other ways, during electrical discharges in oxygen; by the slow oxidation of phosphorus in moist air; by oxidising ether vapour with a hot glass rod; and is found in the neighbourhood of the flame of hydrogen burning in air. As with sulphur, ozone (O_3) has a very strong tendency to throw off its third atom and exist as an ordinary molecule of oxygen (O_2). Because of this it is a very active oxidising agent.

The chief present interest in allotropy to the engineer lies in the fact that it was for a period a working hypothesis of the different characteristics of a metal existing under different conditions. The different phenomena of hard, and soft, and mottled iron, for example, seemed to afford an excellent example of allotropy in metals, as did also the remarkable facts published by the late Sir W. C. Roberts-Austen in his classical Cantor lectures relating to gold and copper. In these and other cases the addition of elements almost infinitesimally minute in quantity, produced most radical differences in the resulting compound, or mixture, for it was uncertain what was really happening. The very small particles of antimony, bismuth, lead, or other elements added to gold seemed utterly incapable either of diffusing themselves through the mass, or of entering into chemical union with the immensely larger body. The remarkable differences produced by the sudden or slow cooling of iron containing carbon, though known well enough in everyday practice, seemed inexplicable, excepting on the allotropic hypothesis, which, however, did not afford any real explanation of the *modus operandi* of the processes going on. At the present time the Allotropists seem to have been driven off the battle-ground by the microscope, an instrument which few thought of much value in metallurgy, except as a dilettanti pursuit. What the microscope has shown is this;—that the masses of the principal metal are unchanged in themselves by the entrance of the alloy into their midst. But the alloy insinuates itself between the masses, separating, segregating, laminating, and generally weakening the whole lump. It is not that the iron or gold or copper are changed, but that they are weakened by the presence of a parasitic element which is often undesirable. *See* **Microstructure of Metals**.

It is difficult to state the case for both theories without going deeply into the history of the researches on the changes which are produced in iron containing carbon. These will be treated with reasonable fulness under iron, so that here we will assume a knowledge of that subject.

The differences between the Allotropists and the Carbonists may be tersely put in this way. The Allotropists hold that iron (around which the controversy has chiefly taken place), which exists in different forms, hard, soft, and in a stage between the two, exists thus by value of modification in the iron, produced by carbon. The Carbonists hold that these changes in the state of iron are produced by changes in the condition of the carbon. The three states of iron are ever present to the foundryman, who has always been unconsciously a Carbonist, because it has always been held that the hard or white, soft or grey, and the mottled or medium soft iron, were states caused mainly by the relative proportions in which the combined, or the graphitic forms of carbon were present. Carbon is an allotropic element, and it seems therefore unnecessary to attempt to explain obvious facts by the assumption of an allotropic condition in the iron itself.

Alloys.—In no department of metallurgy has greater advance been made during recent years than in the study of alloys. And this term is employed in a vastly more comprehensive sense than it was only a few years since. It now includes all the irons and steels as well as the copper alloys, or those of tin, zinc, lead, &c., or those of the precious metals. The subject has been attacked from the mechanical and the chemical side, and the microscope has proved a most valuable aid in these researches. A new literature has been created dealing with this subject, and the names of a few workers in the field have become almost as familiar as household words. The Institution of Mechanical Engineers has fostered a long series of original investigations in charge of an

Alloys Research Committee, whose labours go back to 1890, and who have issued several valuable Reports, published in the Proceedings of the Institution. The late Professor W. C. Roberts-Austen, F.R.S., was the leading spirit of this Committee.

Outside work has been done by Osmund, Gautier, Stead, Turner, Sorby, and others, to whose labours frequent reference must be made in these volumes. The subject of alloys, using the term in its latest modern sense, is not only most fascinating, but one which promises to effect changes in the older methods of those who have to produce and work in metals, in the irons, the steels, copper, and the other commercial metallic elements.

It has always been known in a practical way how a very small proportion of an alloying element is able to effect a most extensive change in the physical characteristics of the alloy produced. The question was long disputed whether an alloy was a simple mixture, or a true chemical compound. For the first it was argued that some metallic elements would not mix properly with others, as lead for example with copper or brass, liquation taking place, or tin with copper, appearing as white spots in the castings, hence the reason for making a preliminary mixture or a "temper" in some of the copper alloys. For the second, the fact that a practically new metal is produced by alloying in different proportions, such for example as soft brass at one extreme, and bell, or speculum metals at the other, favoured the belief in chemical combination. Both are right in certain cases; with suitable mixing the fact of chemical combination is undoubted. Along this line of research many of the most interesting results of recent years have been achieved.

Much of the research of Sir W. C. Roberts-Austen was undertaken to investigate the properties of metals based on the law enunciated by Newlands and Mendeléef, expressed thus: "The properties of the elements are a periodic function of their atomic weights." It was known that the effect of impurities added to gold was nearly proportional to their atomic volume, but it was not known whether this held good for other metals. The researches of Mr Osmund had seemed to indicate the fact that the action of impurities on iron was in accordance with the periodic law. The foreign elements, the influence of which on iron he had studied, are ranged below in two columns, in the order of their atomic volumes, obtained by dividing their atomic weight by their specific gravity.

I.		II.	
Carbon	3·6	Chromium	7·7
Boron	4·1	Tungsten	9·6
Nickel	6·7	Silicon	11·2
Manganese	6·9	Arsenic	13·2
Copper	7·1	Phosphorus	13·5
		Sulphur	13·7

The effect of these elements on iron will be found under **Iron**. Just here we remark that iron is an exceedingly complicated substance even as an element. For pure iron exists in two varieties, the α, or soft, and the β, or hard quality, and impure irons are affected greatly by the presence of the foreign elements, which while detracting from the purity of the metal, add to its value physically and commercially, and an intimate knowledge of which lies at the basis of a scientific treatment of iron and steel in the shops.

Numerous experiments have been carried out, which have had for their object the determination of certain matters connected with the effects of alloying elements on the rate of, and method of cooling, and temperature of the alloys at the "freezing point," or the point when solidification commences. Light has been sought on the behaviour of the alloys employed by engineers, by noting that of alloys of the precious metals, particularly silver and gold. It is proved that alloys are not homogeneous, except in certain proportions which vary in the case of different metals. Levol concluded that the only homogeneous alloy of silver and copper was that containing 71·893 per cent. of silver, and 28·107 per cent. of copper, and that this is a definite combination of the two metals, having the formula Ag_3Cu_2. Sir W. C. Roberts-Austen found that a cubical mass of silver alloy measuring 45 mm. or $1\frac{3}{4}$ inches on the side gave different analyses at different planes. The alloy contained 92·5 per cent. of

silver, and 7·5 per cent. of copper, and it was cooled rapidly. Then it was found that the silver was richer by 1·28 per cent. at the centre of the cube than at the external corners. This partial separation of the alloying elements, known as liquation, is a phenomenon familiar to brassfounders and plumbers as occurring in alloys of copper, lead, tin, and zinc.

The term "eutectic alloy," generally accepted, and employed by metallurgists, was first given by Guthrie to the residual alloy which is left finally as being the last portion of a mass to cool. The first portions of an alloy thrown off in cooling have definite atomic proportions, but the final or residual alloy does not contain its constituents in due atomic proportions. This eutectic alloy is the most fusible.

For many years observers have followed a course of experimenting in which alloys have been regarded as resembling saline solutions in their method of crystallisation. The analogy lies in this, that saline solutions in freezing, liquate, or reject a portion of the fluid part of the mass, the "mother liquor," after the bulk of the salt has crystallised out. This corresponds with the eutectic alloy. But the common alloys have several such liquations;—there are four at least in the copper-zinc series, and six in the copper-tin series; meaning by "series," the range of all the possible unions which can take place in these metals.

The cooling of an alloy is represented graphically by a curve passing through vertical ordinates which represent temperature, and horizontal abscissæ which represent time. As the mass cools, the course of the cooling curve runs obliquely downwards, until the metal begins to "freeze," or solidify. There is then a pause in that course, represented by a horizontal line, during which period solidification is going on. This may occur quickly, but generally it is delayed. When the solidification is complete, the curve continues its oblique downward course until it reaches atmospheric temperature.

Photographic records of the cooling of silver-copper alloys have shown that more than one freezing point occurs, which is considered to be due to the falling out of differently constituted alloys from the mass. Heat also is evolved at these points. The term critical point, or points, is applied to those at which freezing, or solidification occurs.

Gold, which has been freely employed by Sir W. C. Roberts-Austen in experiments on the behaviour of alloys, offers many advantages over iron in researches of this character. It can be prepared in a very high degree of purity, and it is not liable to oxidation. Experiments on it were conducted when alloyed with bismuth, platinum, silicon, manganese, aluminium, silver, and other elements. A study of the effects of aluminium proved the most interesting to engineers, because of the connection of the latter with iron. The gold combined with it most readily, and showed a marked granular structure. The physical properties of the gold were completely disorganised, the point of initial freezing was lowered, the metal only partly solidified during a long range of temperatures, and it could easily be poured at several hundred degrees below its initial freezing point.

The fact that there is a direct connection between the melting point of an alloy and its mechanical properties has a practical bearing in the case of those alloys which have to be subjected to heat treatment in manufactures.

Weakness is a result of the alloying of a strong metal, having a high melting point, with a minute quantity of one that is weak, with the concomitant of a low melting point. A great distinction must, however, be made between such minute quantities, and large proportions. A trace of a metal with a low melting point and large atomic volume renders the metal with high melting point weak. But a large quantity of the first named will often produce an alloy stronger than either one of its constituents possesses.

Some of these facts have long been known by workers in metals, but not understood. They appear now to be related intimately to the fact that the majority of alloys have more than one freezing point, or point at which solidification takes place. Experiments have indicated that when alloys have in addition to a main freezing point, subsidiary ones, the last named is usually associated with low tenacity of the alloy.

In experiments on copper-bismuth, and silver-lead alloys, it has been found that the upper

freezing point, occurring at a comparatively high temperature, which increases with the percentage of the less fusible metal, represents the beginning of the crystallisation of this less fusible constituent in a nearly pure state. But the lower freezing point, which occurs at a uniform temperature for a particular series of alloys, coincides with the freezing of the eutectic alloy, or the one which is more fusible than any other.

Mr Alfred Stansfield obtained photographic curves illustrating the freezing points of the copper-tin alloys. While pure copper has a single fairly sharp freezing point, during which the temperature falls but slightly, the addition of successive increasing percentages of tin lowers the freezing point, and the curve of this point becomes steeper. Also, alloys containing about 80 per cent. of copper solidify in three distinct stages, while those having from 50 to 25 per cent. of copper solidify in four stages.

Another interesting point brought out was that while an alloy as a whole will freeze at a certain temperature, a small portion remains liquid for a considerable time, and does not freeze until a great drop in temperature has taken place. For example, a 90 per cent. of copper alloy, solidified at 1,830° Fahr., while a small portion remained liquid down to 1,420° Fahr. The alloys which showed this property in the most marked degree were those containing more than 50 per cent. of tin.

No alloy of tin and copper which contains more than 5 or 10 per cent. of either metal solidifies as a whole, but there are two or more groups which freeze at different temperatures. This warrants the belief that though definite chemical compounds may occur within an alloy, no alloy as a whole is a simple compound. The various groups formed are unstable in character. Probably the sudden changes which occur in the physical properties of alloys may be due to the formation and disappearance of these unstable groups. Other points arise in the study of alloys, which relate to electrical conductivity, and which will be treated in the section relating thereto. For the present they are merely noted.

The study of these processes which go on during the solidification of alloys, with varying results in the alloy produced, promises to put much of the old rule-of-thumb experience on a more exact basis. It seems as though an exact science of alloys were in process of evolution, by the building up, and correlation of a vast number of experiments. Compounds are formed either while the alloys are in a state of fusion, or at the instant of solidification; some are stable, others are not, their physical properties differ, and the elements of time and temperature affect the results. Practical men will understand exactly how these problems are sources of trouble and uncertainty in the melting of brass, iron and steel.

A very important fact which has been brought out by the study of alloys, in which the irons and steels must be included, is the influence of minute quantities of foreign elements, so small sometimes as one hundredth part, or less, of 1 per cent. The mystery which is as yet unexplainable is in what way do these minute particles act on the mass; one particle, say, among ten thousand particles of another character? Chemical composition does not afford the explanation, but diffusion may be the cause. For if metals will diffuse even in the solid, as we know they do, they should do so much more readily at high temperatures. The truth is, the mysteries of the metals and alloys deepen with further research, and the farther the study progresses, the broader do its bounds seem to extend. But a net result is, that light is being thrown on many of the problems of the shops, and the reasons are found for many operations which have been established, though not understood. It is now known certainly that neither chemical composition, nor mechanical testing, can stand alone in determining the physical characteristics of alloys for certain work. To these must be added pyrometric investigations, and particularly the light which these throw on the formation of eutectic alloys.

Professor John Goodman discovered certain facts which corroborate in a striking way the inferences of Sir W. C. Roberts-Austen as to the injurious influences which minute quantities of the weaker elements of an alloy exercise upon the stronger. In this case, however, the results were rendered apparent in a different way, that of increasing friction in anti-friction alloys.

Suspicion was aroused first by the fact that some alloys of Babbitt metal, which were supposed to be exactly alike, gave differences in frictional results, in some cases amounting to nearly 100 per cent. A close analysis was then made, and it was found that they contained minute impurities, and further research disclosed the following facts:—

That if the impurity added to the alloy were a metal of smaller atomic volume than the main body of the alloy of which the atomic volume was roughly 17, the friction was largely increased. But if the impurity added were a metal of larger atomic volume, the friction was reduced, provided the amount of the addition did not exceed a certain limit.

Thus, taking aluminium, with an atomic volume of 10·6, the addition of a tenth of 1 per cent. would produce from 20 to 30 per cent. increased friction. Taking bismuth, having an atomic volume of 21·1, the addition of a tenth of 1 per cent. produced a slight reduction in friction, but three-tenths of 1 per cent. increased it. About 0·25 per cent. addition gave the best results. But 1 per cent. increased the friction greatly. These results bear out what is well known by mechanics, that Babbitt metal must be very pure, and that much cheap Babbitt is sold which is worthless.

There are numerous cases in which for manufacturing purposes the purity of a metal would unfit it for its duties. A pure cast iron would be useless. There could be no temper steel apart from carbon. Although copper is best for general purposes when pure, an exception occurs in the material used for locomotive fireboxes. Thus, the tenacity of pure copper at 300° Cent. or 570° Fahr. is 9·38 tons per square inch, with an elongation of 34·6 per cent. But according to experiments by Sir W. C. Roberts-Austen, copper alloyed with 0·2 per cent. of arsenic has a tenacity of 12·6 tons per square inch at the same temperature. Thus, the alloyed material is better able to withstand the fire than the pure metal, and explains the preference of locomotive builders for old brands of copper. Professor Hampe has shown that a pure copper wire has an initial tenacity of 21·03 tons per square inch, but a similar wire alloyed with 0·351 per cent. of arsenic has its strength raised to 32·26 tons. If the proportion of arsenic is increased to 0·808 per cent. the strength is reduced to 29·7 tons. Antimony produces a similar effect; 0·26 per cent. of antimony raises the strength of the wire to 32·96 tons, and an addition of 0·529 per cent. raises it to 34·77 tons. These are at atmospheric temperatures. Bismuth has a contrary effect, a mere trace weakening the copper greatly.

For mixtures of alloys, as used in foundry work, *see* **Aluminium Alloys, Bearing Metals, Brass, Bronze, Delta Metal, Phosphor Bronze, Iron, Steel.**

Alterations to Patterns.—In the pattern shop more than in any other department of engineering, alterations form a considerable proportion of the work done. The pattern being

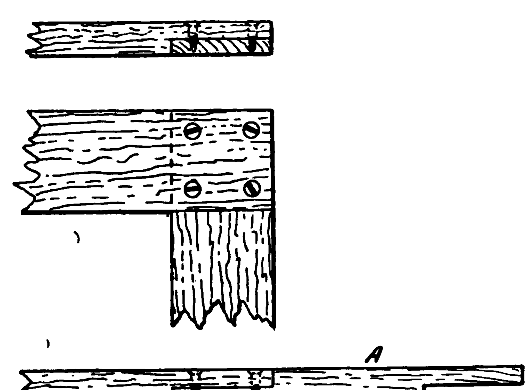


Fig. 36.—A Framed Pattern increased in length, by taking it apart and inserting a lengthening piece *A*.

the model from which the casting is produced, it follows that it is often more economical to alter an old pattern than to make a new one, when a casting but slightly different to an existing pattern is required. A number of things have to be taken into consideration in deciding about such modifications. If many castings are required from a pattern, the idea of altering an existing one for the purpose must be abandoned. If only one casting is required, the pattern can often be of a very makeshift character, even though it involves work in the foundry that would not be justified if a number had to be made from it. It is often the case that an existing pattern might

easily be adapted, and yet there is a strong objection to making the necessary modifications in it, because it would have to be altered back

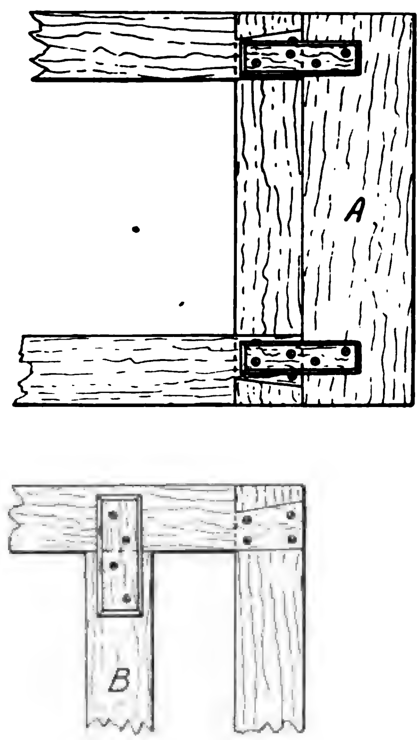


Fig. 37.—Shows a Framed Pattern extended by screwing on a piece *A*; shortened by inserting a strip *B*, as a guide for stopping off by.

again, and would, besides the double work, be considerably depreciated and weakened in the process. In other cases the alterations

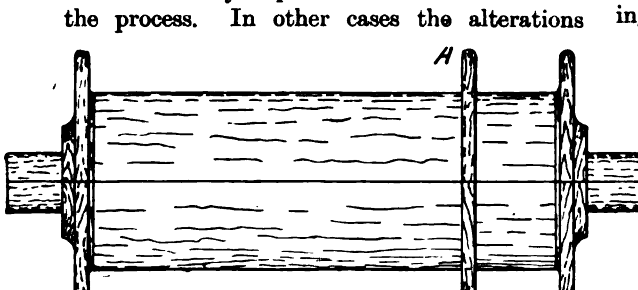


Fig. 38.—Illustrates how the Pattern of a Drum is shortened by fitting a body flange *A* to the length required, to be "stopped off" in the mould.

required may be so great that a new pattern is cheaper. The nature and extent of these have to be considered, but when patterns of one standard form are required repeatedly it is seldom advisable to alter them. When a pattern is of so unusual a character that it is never likely to be wanted again, there is no objection to altering it for something else, if possible; but even then, its size, and the amount of work put into it, should be considered. It is unwise, for instance, to practically destroy a

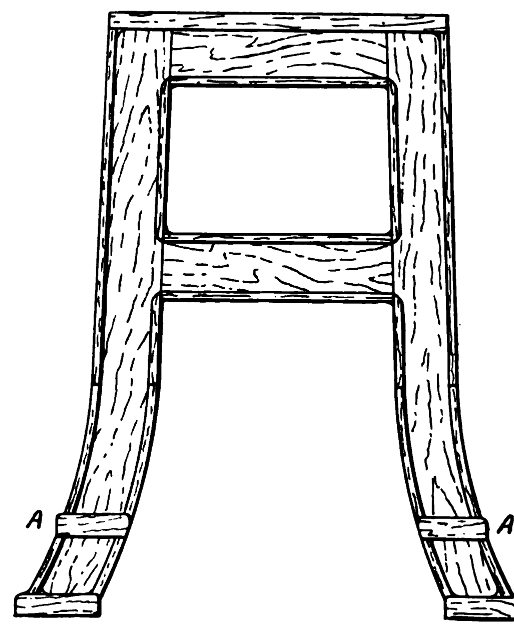


Fig. 39.—A Standard Pattern, the Casting from which is to be reduced in height; the new feet *A A* indicate where the mould is to be stopped off.

small, intricate pattern for the purpose of turning it into a very plain one, that would consume very little time or material to make new. On the other hand, a large, plain pattern which occupies a great deal of store room may often with advantage be taken apart as soon as done with, and the material used for other purposes.

Patterns are often constructed with the intention of making them serve for two or more castings slightly differing. In such cases, especially if the change has to be made a number of times, they are built as far as possible specially to facilitate the alteration. The parts may be made separate, detachable, and interchangeable with each other. Cutting the pattern is avoided if possible in all cases. There is always much less

objection to adding parts, Figs. 36 and 37, which may be removed again, than to cutting away portions. The latter practice can be avoided, and the same end achieved by filling up a portion of the mould instead of removing that portion from the pattern. The pattern itself then remains unaltered excepting by the necessary temporary additions, Figs. 38, 39, 40, and the required alteration is made in the mould, after the pattern is withdrawn from it. This involves extra work in the foundry, and is not resorted to when large numbers of castings are required from a pattern. To accomplish this result, the patternmaker marks on the

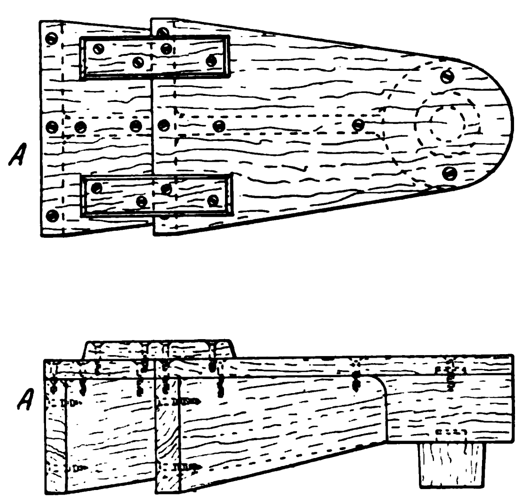


Fig. 40.—Illustrates the Extension of a Bracket Pattern by a new foot *A*, battened on, the battens and original foot to be stopped off.

pattern the parts which are to be stopped off, and provides the moulder with pieces of wood of suitable shape for ramming the sand against in filling the spaces up. These "stopping-off" pieces are made to fit into the mould at the location just beyond which the filling up is to be done. When placed in position they enclose the space to be filled, and provide a body of wood of the same shape, and in the same position, as that portion of the pattern would have occupied if the pattern had been the right shape and size. When the stopped-off portion of the mould is filled with sand, the stopping-off piece is withdrawn. This device, therefore, is not strictly speaking an alteration to the pattern, though great modifications in the shape of the castings may be produced by it. Where there is no special objection to it, it is simpler to cut the pattern than to go to the trouble of stopping off, though the amount of work involved in either case varies greatly.

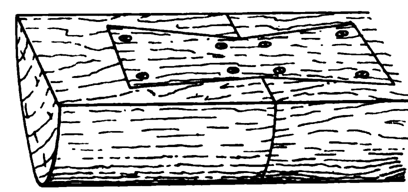


Fig. 41.—Extension of Pipe or Column with Dovetailed Tongue Piece.

The same effect as that of altering the pattern may often be produced by altering its core box, so that metal is added to or removed from the casting by a modified form of core. Portions of castings are often stopped off by making a core to fill a space that would otherwise be metal.

In most cases alteration in a pattern involves additions, and this is very simply accomplished by putting the required amount on the pattern. As a rule it matters very little how this is done, so long as it is substantial enough to be moulded from. The essentials of a pattern regarded from this point of view are that its shape and dimensions shall be correct, and remain so with reasonable usage. As an altered pattern is seldom quite equal to a new one in these respects, and the alterations are often made for one casting only, the dimensions are

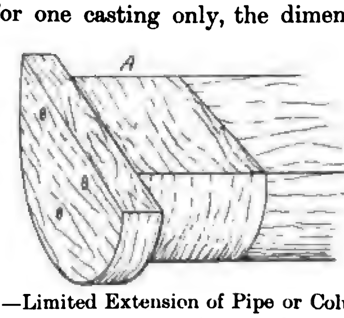


Fig. 42.—Limited Extension of Pipe or Column, with an insertion piece *A* screwed on end.

increased in whatever way is quickest and most convenient. Where a considerable increase has to be made, as in an extension which must be rigidly held in line with the body of the pattern,

battens are generally used, as in Fig. 40, and are themselves stopped off, or a dovetail is used, as in Fig. 41, or pieces are screwed on, Fig. 42.

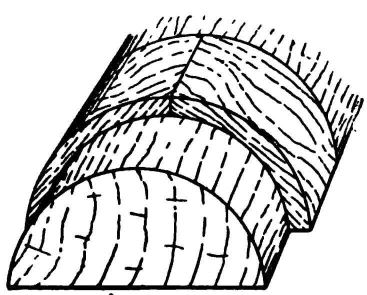


Fig. 43.—Limited Extension of Cylindrical Pattern, by fitting sweeped pieces round the print.

Where curved surfaces have to be thickened up, wood is often bent round, assisted when necessary by steaming, and running saw-cuts across

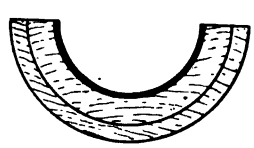


Fig. 44.—Lining up the Bore of a Brass Bearing with Sheet Lead.

to facilitate the bending, or sweeps are cut, as in Fig. 43. When the amount to be added is only slight, there are other substances that can

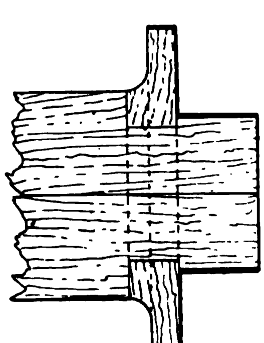


Fig. 45.—The Diameter of a Print, and Flange slightly increased by wrapping Sheet Lead around the outside.

be more readily applied than wood. Leather, and sheet lead are then used, Figs. 44, 45, or other materials that will bend, and possess a smooth surface, and are of the thickness required. For small amounts there is nothing better than thicknesses of paper, glued or shellaced on. Another common method of thickening a cylindrical body is to plane a number of

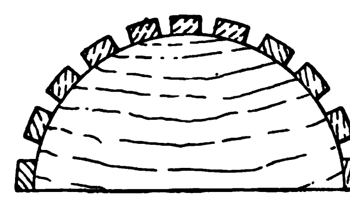


Fig. 46.—Enlargement of Pattern of Drum, Column, or Pipe, with Strips.

strips of wood to the thickness required, and brad them on longitudinally close together, or with narrow spaces between, Fig. 46. This is sufficient to give the correct diameter, and with a little extra sleeking, the mould is all right.

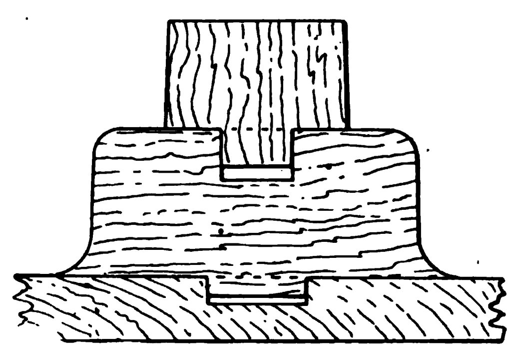


Fig. 47.—Shows how Bosses and Prints are made interchangeable by means of Studs.

Core prints are usually altered by taking off the old and substituting new. This frequently has to be done in the case of plain cylindrical cores, and in such cases a stud hole should be bored at the correct centre on the pattern, and prints be pro-

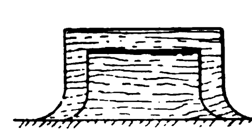


Fig. 48.—Shows how a Pattern Boss which cannot be conveniently removed is enlarged by fitting a Shell Boss over it.

vided with a stud to fit it, Fig. 47, so that change of print, or removal of print by the moulder if he wishes, can be done without any trouble.

Figs. 47 and 48 also show how bosses are altered in size.

Core prints can also be thickened up similarly to the patterns themselves, and core boxes may be lined up in the same way.

Allowances.—This term covers a good deal in mechanical operations of nearly all kinds, and has several different meanings. Since nothing made is ever absolutely correct, or remains permanently unchanged, it becomes necessary to foresee and provide for necessities and contingencies.

As the term is most commonly used, it refers generally to shrinkages, and expansions of metals, to the amounts provided for tooling, clearances for rough or slack fits, and factors of safety for strength, each of which will be treated at length under appropriate headings. Though the necessity for all these is patent, the amounts are not always readily determined apart from much experience gathered in similar circumstances. In the settling of suitable allowances lies much of the difference between theory and practice, between approaching work *de novo*, and following in the lines of safety marked by experience. And as in details apparently insignificant in themselves, so in the great complete structures, and mechanisms generally, the whole history of their development has been one of myriads of allowances made for contingencies, the need for provision against which has been revealed by innumerable failures in their functions and duties. In this sense the highest mechanical achievements are the products of evolution, notably the bridge, the locomotive, the machine tool, the crane, the dynamo, and much beside. Slowly in a tentative fashion minute allowances for various contingencies have been made, which in the aggregate have resulted in structures and mechanisms having little beyond a bare outward resemblance to the original designs.

Alternating Currents.—Alternating currents of electricity differ in several important points from continuous currents. Whether we hold the theory of electricity, by which it is supposed to consist of wave motions in the ether, similar to those of heat and light, but at different rates, and with different wave lengths; or whether we hold, with the advanced scientists, that electric currents are processions of minute bodies, each carrying a small charge of electricity, matters little. The practical distinction is, that when the currents are of the continuous type, the waves, or the processions of charged bodies, are always in one direction; and with a given pressure and given resistance between any two points, the current strength is always the same. With continuous current generators and motors the same terminal of the dynamo is always positive, unless the connections are altered, and with a given external resistance the current passing through it is always the same.

But with alternate currents, all this is changed. These, as their name implies, are alternating in direction. The direction of the pressures causing currents to pass, and that of the currents themselves, are reversed in modern

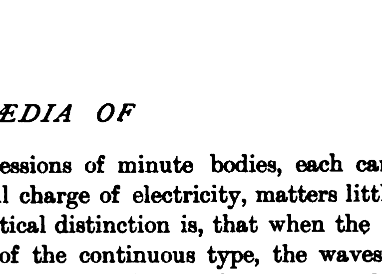


Fig. 49.—Diagram showing the Variations of Alternate Currents in each Cycle. The horizontal distances represent time, the vertical heights, pressure, or current.

practice from 25 times to 60 times a second, the terminals of generators and motors being alternately positive and negative. In the earlier alternate current apparatus the reversals were as many as 166 per second, while in what is called high frequency apparatus, used only, at present, for medical purposes, the numbers of reversals are as many as a million per second. And this is not the whole difference. In addition to reversing the number of times per second named, the pressures and the currents are also constantly changing in value, from instant to instant, throughout each period or cycle. A cycle of an alternating current consists of; commencing from zero O, Fig. 49, a gradual rise to a maximum Y, followed by a gradual fall to zero X, this being followed by a rise to a maximum in the opposite direction Y^1 to that of the previous half cycle, followed

again by a gradual fall to zero o[1], a gradual rise in the first direction, and so on. The two complete periods containing a rise to a maximum, and a fall to zero, in the two directions make a complete cycle. It will be understood that all that has been stated above refers both to pressures and to the currents they cause, though there are some peculiar features intro-

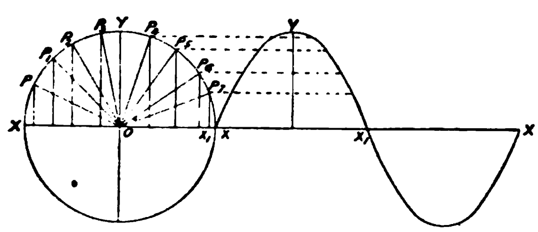


Fig. 50.—Showing how the Variations in the Value of the Volts or Ampères in an Alternate Current Service, are referred to a Sine, or Harmonic Curve.

duced in this connection, in consequence of the constant variation of the pressures and current strength.

The first question the practical engineer meets with, in alternate current work, is, what figures is he to use for pressures and currents, in order to enable him to arrange for his cables, &c.; and the answer is, there is an average or virtual pressure and currents, Figs. 50, 51, used in the same way as the pressures and currents are used in continuous current work, and which mean the same thing, in the sense that incandescent lamps made to work with continuous currents will work with alternate currents, provided the virtual volts of the alternate current service are the same as the volts of the continuous current service. Any incandescent electric lamp, purchased anywhere, provided it is properly made, marked for 100 or 200 volts, will work on continuous current or on alternate current services equally well. The virtual volts of an alternate current service then are the volts that will furnish the same current in an incandescent lamp, or any other conductor, not subjected to inductive influence, as would be furnished by a continuous current voltage of the same value. The virtual ampères of an alternate current service are the ampères that will give the same heating effect, under the same conditions, as the continuous current of the same strength. As the pressure rises and falls, and as the currents rise and fall, there is some pressure and some current strength which represents the pressure and current that would produce the same effect, if there were no alternations, and no rising and falling. This pressure and this current are found by what is termed the square root of the mean square value. The heating effect produced by a given current varies as the square of the current strength, if the resistance is constant, as it is in an incandescent lamp when it has attained its working brightness. The heating effect produced by any given pressure, when the resistance is also constant, depends likewise on the square of the pressure in volts. Evidently then the quantity wanted is the square root of the quantity which produces the equivalent of the heat produced by a certain pressure or current when continuously applied, and the quantity wanted is the mean of the squares of all the values the pressures and the currents assume during each half cycle. Hence the puzzling quantity, the square root of the mean square value. The heating value of each current and of each pressure is in proportion to its

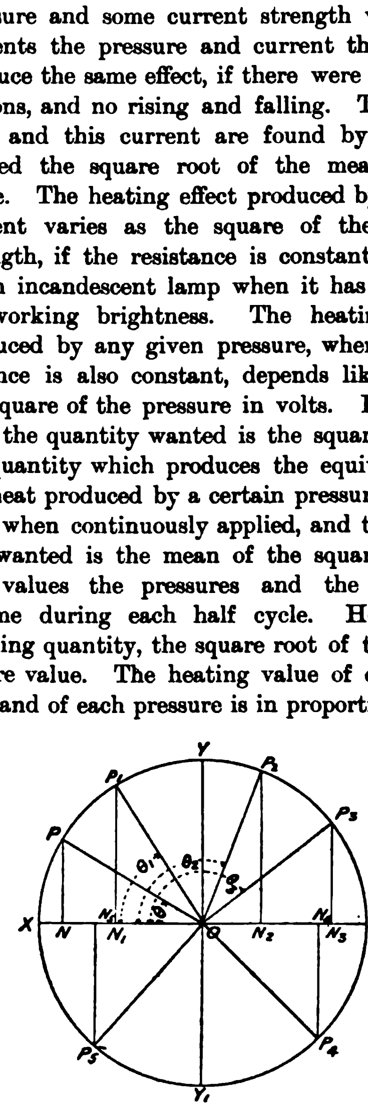


Fig. 51.—Showing how the varying Values of the Volts and Ampères, in an Alternate Current System, are represented by successive angles swept from 0 to 360° by the revolving radius.

square, and the mean value must be the mean of the squares of all the values assumed, and the square root of this will be the average value we are looking for. It should be mentioned that heating effect is independent of the direction of the current, and that the temperature assumed by any body depends upon

the heat delivered to it, and that radiated, or otherwise taken from it. Each increment of current or of pressure brings some heat, depending upon the square of its value in ampères or volts, and some heat remains in, say the filament of an incandescent lamp, after the current has ceased, hence there is an average rate of delivery of heat to the filament, and this is found by the formula mentioned. It will be seen, however, that a certain minimum number of currents are necessary for lighting by alternate currents, or there will be a visible winking of the light. If the currents which succeed each other allow time for the filament to cool before the next current arrives, or before the active part of it does, it will be distinctly notice-

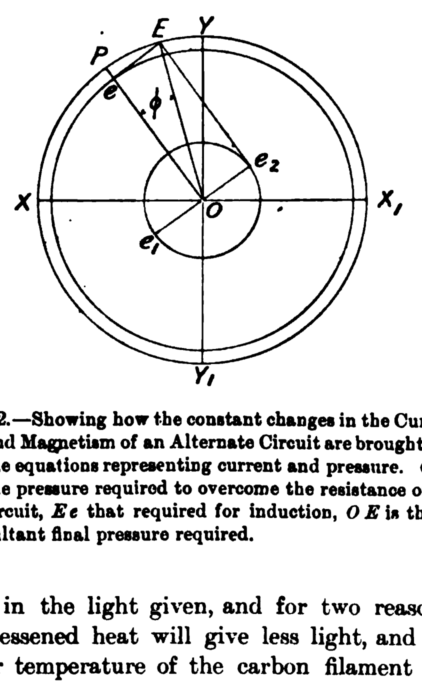


Fig. 52.—Showing how the constant changes in the Current and Magnetism of an Alternate Circuit are brought into the equations representing current and pressure. *Oe* is the pressure required to overcome the resistance of the circuit, *Ee* that required for induction, *O E* is the resultant final pressure required.

able in the light given, and for two reasons: the lessened heat will give less light, and the lower temperature of the carbon filament will allow less current to pass with any given pressure, hence reduced light from the two sources. The above considerations have fixed 25 complete periods per second as the lowest periodicity, under existing conditions. With lamps having larger and thicker filaments than those usually employed, such as higher candle power lamps, or lower voltage lamps, the periodicity of the service may be lower. In fact, with very thick filament lamps, such as those used for 200 c.p. and above, even the effects of the explosions of an old pattern gas engine are not noticeable.

The square root of the mean square values is expressed by the fraction 0·707. That is to say, the virtual volts are 0·707 of the maximum volts reached, and the virtual ampères 0·707 of the maximum ampères in any service, and conversely the maximum pressure is 1·414 times the virtual volts, and the maximum current 1·414 times the virtual ampères. The virtual volts and the virtual ampères are sometimes written as effective volts and ampères. The next trouble in connection with alternate current services is, that the calculation for the power is all wrong. With continuous currents, —multiplying the volts by the ampères, and dividing by 746, will give the rate that work is being done at, or that energy is being expended in any circuit, or any part of any circuit, in horse power, but with alternate currents this is all altered, and because the current does not pass at the same instant as the pressure to which it owes its existence. The current lags behind the pressure, or it may be in front of it, according as the electro-magnetic or electro-static conditions are stronger. When an electrical pressure is applied to a conductor, the current does not reach the end of the conductor until a magnetic field has been created around the conductor, for the full length; and at the same time the condenser of which the conductor forms a part is charged to the full capacity of the available pressure. When the pressure is removed the magnetic field closes in on the conductor, returning energy to it, and the condenser of which the conductor forms a part also discharges the current it received. When a change is made in the pressure, or the current strength, changes also take place in the magnetic field and the condenser charge. So that as alternate currents are constantly altering their pressures and current strength, there is a constant interchange of energy between the conductor and the magnetic field and the condenser, and this causes, as explained, a lag, or a lead of the current, behind, or in front of the pressure creating it. The important fact is, that the current to be used in calculating the power absorbed by any circuit is not that which Ohm's law would dictate. Sometimes it is larger, but more usually

it is smaller, and the qualifying factor that will enable the engineer to calculate his power is the Cosine of the angle of lag, of the current behind the pressure, Cos. ϕ as it is commonly expressed. It is usual to express the changes that take place in the pressures and currents of an alternate current service by successive angles, Figs. 52-54. Taking the complete cycle as 360 degrees, half the cycle is represented by 180 degrees, a quarter by 90 degrees, and so

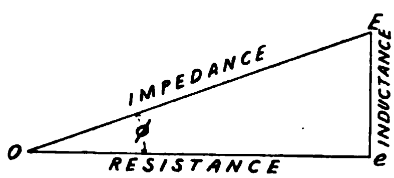


Fig. 53.—This is an Enlarged Form of the Triangle shown in Fig. 52. It will be noted that the angle of lag ϕ is given. The quantities are here given as resistance, the ordinary ohmic, as it is called, inductance due to changes, and impedance the resultant.

on. The first maximum is represented as 90 degrees from the origin, the second zero as 180 degrees from the origin, the second maximum as 270 degrees, and so on. It will be evident that the pressure and current at any instant can be represented by lines making different angles with the line of origin, and the angle between the two will represent the angle of lag, or of lead, of the current, with respect to the pressure. The Cosine of this angle, ϕ, represents the factor that has been mentioned, the power factor, as it is termed; the formula for the power delivered to, or absorbed by any alternate current circuit being $W = EC \cos \phi$, where $W =$ the rate of doing work, E the virtual volts, and C the virtual ampères.

It will be remembered that the Cosine of any angle is measured by the base divided by the hypotenuse, and as with the angle made by a line revolving around a centre the radius which forms the hypotenuse is constant, the value of the Cosine depends upon the length of the base. At 0 degrees, the value of the base is 1, the base coinciding with the radius, while at 90 degrees the base goes out altogether, or is equal to 0, the value of the Cosine varying between these limits, according to the length of the base line. Hence when the angle of lag is 0 degrees, or the pressure and current coincide, Cos $\phi = 1$. This is the case of the continuous current, and of certain cases with alternate currents. When the current lags 90 degrees behind the pressure, Cos $\phi = 0$, or the peculiar case is reached where no power is delivered, or absorbed by the circuit subject to those conditions. The standard power factor is taken as 0·8 usually, and many makers claim to be able to ensure 0·9 and over. The power factor depends upon the apparatus included in the circuit. Incandescent lamps have no induction, and the power factor, so far as they are concerned, is 1·0, but there is always the generator, which must have a power factor of its own, and each motor adds to the inductive effect, and reduces the power factor.

It should be noted that, while the current and pressure do not coincide, only a portion of the current being used for practical purposes, the whole of it has to be generated, and this leads to an increase in the size of the cables, and to other things, since more current has to

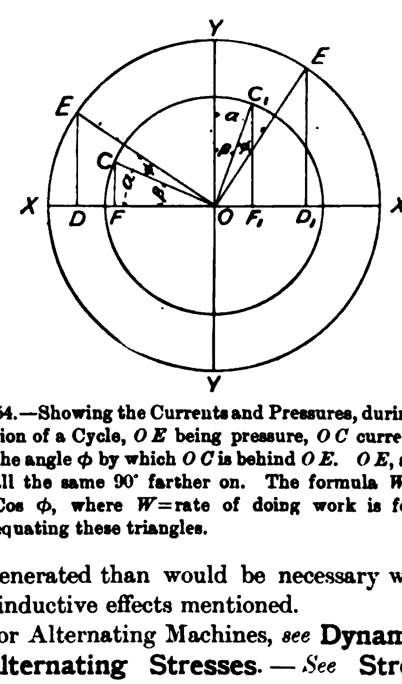


Fig. 54.—Showing the Currents and Pressures, during a portion of a Cycle, *O E* being pressure, *O C* current, with the angle ϕ by which *O C* is behind *O E*. *O E*, and *O C*, all the same 90° farther on. The formula $W = E \times C$ Cos ϕ, where W = rate of doing work is found by equating these triangles.

be generated than would be necessary without the inductive effects mentioned.

For Alternating Machines, *see* **Dynamo.**

Alternating Stresses. — *See* **Stresses, Fatigue of Materials.**

Alternative Methods in Shop Practice. —This aspect of workshop practice looms immensely larger now than it did only a few

years ago. Its development is due to the rapid evolution of a few machines, tools, and adjuncts of special types; chief among which are the moulding machines, the power hammers, smiths' dies, the numerous turret lathes, and automatic screw machines, the vertical boring mill, the milling machines, the special gear cutters, and the precision grinding machines.

Alternative methods fall under two heads, one being that which relates to the conduct of the shops, the other that which is due to the introduction of new and improved machines, and methods associated with them, the economical importance of which increases very rapidly.

The questions that arise may be classified in the following ways:—Sequence of operations, methods of construction, division of tasks, degree of accuracy desired, the performance of numbers of similar operations at one time, or of miscellaneous tasks. In the case of work which goes through more than one department, the question of lessening the amount of labour in one at the expense of that in another has to be considered. Some of these alternatives we will now consider.

The first and most important fact with which we are met in connection with the work performed by machines is, that the new machines have changed the point of view from which processes have been so long regarded. The work is considered not so much from the standpoint of what is, or has been customary, as of the ultimate results which are desired. The difference between the old and the modern shop is that the ideal of the latter is to break away from the trammels of use and wont, and to arrive at results by more excellent, *i.e.* economical ways. Men who are engaged in this class of shop will understand the meaning of this more readily than those in antiquated works. For example, because a certain kind of piece has been tooled by planing for years past, the modern manager would not hesitate a moment about disturbing the mental equanimity of the planer hand by sending such work to a milling machine, or to a surface grinder, if better results could be obtained with a smaller expenditure of time. As in almost all cases there are at least two or three ways available for arriving at identical results, the alternative which is least expensive is selected. There is more than one method of producing plane surfaces, or cylindrical forms, external and internal, and more than one method of cutting screw threads. There are also two or three or more alternative methods of producing many forgings, and many castings, and the manager must become thoroughly acquainted with each of these if he is to derive the fullest benefits from the possession of modern machinery. The employment of the best machines alone is not sufficient without the exercise of intelligence in their use.

Broad views are more than ever necessary in the utilisation of machines, statements concerning which are difficult to postulate, except in the form of generalities. Some of the differences in old and present practice are apparently contradictory. Thus, on one hand it is true that an object generally desired is to perform all the tooling on a job when possible on one machine, at one fixing; while on the other hand it is equally true that economy is often sought by performing operations on the same piece of work on different machines. Yet the two methods are not opposed to each other, because they apply to wholly different classes of work. Two factors, among others, are important in the selection of these methods, the first being the mass of work, which renders change of position undesirable, and costly; and which has been the principal cause of the development of large numbers of machines that combine several functions, as planing, drilling, tapping, milling, &c., and also of the growth of portable machines. The second is specialisation, and manufacture of parts in quantity, which often favours the distribution of tasks between two or more machines, as lathe and grinder, or roughing and finishing lathe, or planer and milling machine, &c. Apart from this also many jobs lie on the border line; so that careful observation, and balancing of costs, either estimated, or gathered from previous experience, are necessary. The pre-occupation also of machines has to be taken into account. A job is often sent to a particular machine, not because it is the most economical tool to use, but because it happens to be unoccupied for the time being, and machines that are allowed to

lie idle long are white elephants. Another point is that there are certain rivalries going on in the machine shop, as for example between the planing or shaping, or slotting, and the milling machines; and between the common lathes, and the turret lathes, and the automatic screw machines; or between the general, and the special forms of gear cutting machines; or between fixed and portable machines; and when jobs are on the border line there is room for much difference of opinion as to the most suitable machine to use. In very many cases there is of course no question whatever, or room for hesitation, but in many there is, and that accounts for many alternatives in practice.

Foremen often pride themselves on lessening the cost for labour in their own department, but at the expense of another, carrying out the principle of every man for himself. Here the management must make itself heard, and insist on the subject of economy being regarded from the standpoint of the total economies, instead of from those of a particular shop. It is manifestly false economy to save a sovereign in one shop if it saddles another with a couple of sovereigns expense extra. This, however, is very often done, so interdependent are the departments in the engineers' works. It affects all shops, but those specially related are the pattern shop and foundry, and both with the machine shop, turnery, and erecting shop; these last are also in touch with the work of the smithy. And the cost in these related shops must be therefore taken in conjunction, and not as isolated and independent factors.

The greatest controlling factor in the selection of alternatives is the quantities in which similar pieces are made, which opens up the wide question of specialisation, with all that is involved in that: as highly specialised machines, jigs, templets, gauges, the use of stamps in the smithy, of moulding machines in the foundry, the manufacture of large stocks, and the employment of much cheap unskilled labour. It follows that the methods of those shops where specialities are manufactured are almost wholly different from those where a general run of work is produced, and as manufacture is tending unmistakably in the direction of specialisation, the importance of these methods increases. Detailed information on these subjects will be found under numerous heads, but particularly *see* **Automatic Screw Machines, Box Tools, Turret Lathes, Grinding Machines, Jigs, Forging Dies, Moulding Machines, &c.**

Alternator.—*See* **Dynamo.**

Alumina.—*See* **Aluminium.**

Aluminium (Lat. *alumen* = alum).—The isolation of aluminium was predicted by Sir Humphry Davy several years (1809) before it was reduced from its ores. He actually gave the name alumina to the new product before its birth, afterwards changing it to aluminum (1812). In 1824 Oersted achieved partial success, but in 1827 Wöhler first isolated the metal. Not till 1854 did Deville succeed in producing it commercially by chemical means, by heating aluminium chloride with potassium. By this method aluminium was manufactured down to 1890, its price ranging from nearly £20 a pound in 1856 to about 1s. an ounce at the latter period. Though the electrolytic process had been also tried, the cost of battery cells prevented it from being a rival to the chemical. The coming of the dynamo machine introduced a better way, but while the generation of power by coal alone was available, the industry made little progress, though the price dropped quickly to 4s. a pound. But when water power was utilised, the price came down to 1s. 3d. per pound, and the future of aluminium was assured. The present prices of aluminium are mostly below 2s. per pound. This is the price for light castings involving a good deal of coring. Rods and bars are 1s. 8d. or 1s. 9d., sheets from 1s. 4d. to 1s. 6d. Angles, channels, tees, and beams 1s. 10d., tubes 3s. to 3s. 5d. It is an interesting fact that the first great water power installation in Britain (1894) was secured for the manufacture of aluminium. And all the great aluminium factories in the world are now operated by water; at Niagara, in Switzerland, at Neuhausen, by the Rhine, in France, by the Rhone, and at Froges, and St Michel.

The physical properties of aluminium of 98½ per cent. purity may be summarised as follows:—

It can be cast, hammered, rolled, or drawn, be used pure, or alloyed with other metals. Its sp. gr. is about 2·6. Cast in sand it is 2·56, in

metal moulds 2·60, hammered or rolled 2·67, drawn into wire 2·71. A cubic foot of cast aluminium weighs 158·9 lb.; a cubic inch ditto, 0·092 lb.; a cubic foot of rolled Al., 169·5 lb.; sheet Al., 1 foot square by 1 inch thick, weighs 13·9 lb.; a bar of ditto, 1 inch diameter and 12 inches long, weighs 0·91 lb. To obtain the weight of aluminium in castings, bars, or sheets, &c., divide the weight of similar pieces of copper by 3·3, of brass by 3·1, of steel by 2·9, and tin by 2·8. The shrinkage of aluminium castings is about equal to that of brass—about ¼ inch to the foot, or $\frac{17}{64}$ inch. The coefficient of linear expansion of round rods of Al., of 98½ per cent. purity, is 0·0000206 for each degree Centigrade between the freezing and boiling points of water. That of iron is 0·0000122, of tin 0·00001718. Aluminium has a bright silvery-like appearance when drawn, or rolled, or cast in green sand, at a low temperature, or cast in metal moulds. But if cast in dry sand, or poured too hot, it has a bluish-grey appearance resembling lead or zinc. The tensile strength of aluminium diminishes with increase in temperature. According to Chatelier—

A distance of 85 miles from Shawinigan Falls to Montreal has all Al. conductors.

The mean specific heat of aluminium from zero to the melting point is 0·2185, water being taken as 1. Thus, the quantity of heat that would raise the temperature of a quantity of aluminium through 1° Cent. would only raise the temperature of the same quantity of water through 0·2185° Cent. Aluminium is a good conductor of heat, being only exceeded by three metals, thus:—Silver, 100; copper, 73·6; gold, 53·2; Al., 37·96 unannealed, but 38·87 if annealed; tin is 14·5; iron, 11·9; steel, 11·6; bismuth, 1·8.

Aluminium is highly ductile and malleable, but the metal must be free from contamination with silicon and iron. Pure Al. can be hammered nearly as thin as gold leaf. It does not tarnish sensibly on exposure to air, being only inferior in this respect to gold and platinum. Neither does fresh water act upon it. Sea water acts slightly, but for most purposes the pure metal is practically incorrodable. Even sulphide of hydrogen, which darkens silver, has no effect on Al. It is unaffected by nitric

Temperature—Centigrade	15°	100°	150°	200°	250°	300°	400°	450°	460°
Tensile Strength—Tons per square inch	11·68	9·5	8·1	6·3	4·8	3·6	2·4	1·5	1·0

The conductivity of aluminium is rather more than half that of copper. Pure copper being taken at 100, that of Al. is 58·59, at the temperature of 15° Cent. But this is bulk for bulk, not weight for weight. If the latter is taken, the conductivity of Al. is about 91½ per cent. more than copper. A yard of annealed Al. wire of 98½ per cent. purity, ·0325 in diameter, at 14° Cent., has a resistance of 0·05484 ohm, while a yard of copper wire of the same size, and at the same temperature, has a resistance of 0·03150 ohm.

Aluminium is employed for three large transmission lines in North America. It is used over a distance of 154 miles from the Electra power house to San Francisco. The 144-mile line between Colgate and Oakland consists of three Al. and three copper wires.

acid, and only slightly by dilute sulphuric acid. Hydrochloric acid, and solutions of potash or caustic soda, are the best solvents of Al.

The manufacture of aluminium is effected in three stages—first, the production of pure alumina, the oxide of the metal, from its earthy compounds; second, the reduction of the metal from the oxide; and third, the casting and rolling of the metal into commercial forms.

Alumina is found almost everywhere in association with clay, but never in the metallic state. It forms compounds with oxygen, fluorine, silicon, the alkalies, and the acids. These are decomposed by the influence of air and water, forming clays. The principal source of aluminium is the mineral Bauxite, deriving its name from the French town of Beaux, in the vicinity of which it was first discovered. Cryolite is a

double fluoride of aluminium and sodium, containing 13 per cent. of aluminium. A matter of interest is that the ruby and sapphire are almost a pure alumina, and these with the garnet contain large quantities of the metal.

The British Aluminium Company draws on the rich deposits of Bauxite at Glenravel in County Antrim, 35 miles distant from Larne. The analysis of this gives 56 per cent. of alumina, corresponding with aluminium 29·9 per cent., peroxide of iron 3, silica 12, titanic acid 3, and water 26 per cent.

The following is a description of the methods adopted at Larne for the preparation of alumina, and which are due to Dr K. J. Bayer.

The Bauxite is first ground in a disintegrator, down to ¼-inch cubes, falling through a riddle of ¼-inch mesh. All that passes goes into the calciner, while the tailings are returned to the disintegrator to be again ground. The object of calcination is to destroy the organic matters present in the ore, which would prevent the subsequent separation of alumina from the caustic soda in another stage of the operations. The calciner is an iron tube lined with fire-brick, and rotated with its axis at an angle of 1 in 25. It is heated by a furnace at its lower end. The heat passes up through the tube to a chimney, and the revolution of the tube throws the Bauxite from the higher to the lower end, meeting the ascending heat. It falls on a slotted plate, and passes into a cooling tube inclined in the opposite direction to the calciner, and is there cooled by a current of air drawn through the tube by a fan. On leaving the tube it is discharged by a spiral conveyor into a second disintegrator, where it is reduced fine enough to allow it to pass through a sieve having 900 holes per square inch. Thence it is stored to supply small trucks that receive it through a hopper for subsequent processes.

The finely ground alumina is treated first with a strong solution of caustic soda, under steam pressure. A soluble aluminate of soda results, leaving the peroxide of iron, silica, and titanic acid as insoluble compounds. The operation is performed in strong cylindrical kiers, built of steel plates, tested to 200 lb. per square inch, and working at about 80 lb. pressure. An agitator passes through the axis of each cylinder, comprising a 3-inch shaft fitted with light paddles. The caustic soda solution of 1·45 sp. gr. is run in first, and the agitator being started, the mixture is filled in by weight. A charge consists of about 3 tons, on the filling of which the charging opening is closed, and steam admitted into a surrounding jacket. In the course of two or three hours the decomposition is completed, and the mass is blown out into tanks, when it is diluted with water to a sp. gr. of 1·23, after which it is filtered.

The object of filtering is to separate the aluminate of soda from the impurities. It is accomplished in presses, each having fifty chambers, to form cakes measuring 30 inches square, and 1 inch thick. The impurities take the form of red mud, which is retained in the chambers, while the liquid aluminate of soda is run out into filter tanks.

The lyes from the filtering presses are subjected to another filtering process, through cellulose. These last filters are lead-lined vats, having a sieve of ⅛-inch mesh, supported on a frame 6 inches from the bottom. Two such filters are placed one above another. About 50 lb. of cellulose, consisting of papermaker's wood pulp, is boiled down with water, and run upon the sieves to receive the lyes, retaining all the insoluble particles that have escaped the filter presses

The next stage is the separation of the alumina from the soda. In the Bayer process the alumina is set free in the form of hydrate, by an addition of excess of hydrate of alumina, and constant stirring, which takes place in decomposing vessels. In about thirty-six hours 70 per cent. of the alumina has separated from the soda, the agitation has stopped, and the contents are left to settle. The hydrate of alumina settles to the bottom, and the clear liquid is run off the top into tanks. Afterwards the hydrate is pumped out, leaving sufficient for beginning the decomposition of the next charge. The portion pumped out is filtered through presses, the liquor passing into the tanks. The contents of the presses are washed in five stages to remove the last traces of soda, followed by forcing compressed air through the cakes.

The hydrate of alumina is now calcined to drive off the moisture, and the water of hydra-

tion. The temperature employed is about 2,000° Fahr., which, though much higher than is required to leave the alumina in an anhydrous condition, is necessary to render it crystalline, in which condition it is much less liable to absorb moisture than in the other state. After cooling, it is ready to be packed in casks.

The pure alumina, or oxide of aluminium, in the form of a finely divided powder, is shipped in hermetically sealed steel drums to Foyers in Scotland. Here it is reduced by the Héroult process, and run from the electrolytic baths into ingot moulds. Hence the manufacture divides, many of the ingots required for foundry purposes being sufficiently pure for such work; many, however, required for rolled work, have to be remelted and refined. The contaminating substance is cryolite, used as a solvent during the electrolysis, and which is a double fluoride of aluminium and sodium, containing 13 per cent. of aluminium. The metal is refined until it attains a purity of 99·6 per cent. Sometimes when casting, a little cryolite, or similar flux, is added to assist in the liberation of impurities, which then form a scum on the surface. During the melting, the scum which forms on the surface of the crucibles is taken off to recover the aluminium, a whitish powder left contains practically nothing but the cryolite, and some carbon.

Aluminium castings are made from metal melted either in crucibles of plumbago, or sand, or iron. It is also melted on the bed of a reverberatory furnace, lined with basic magnesia bricks. The temperature employed is only a little in excess of the melting point of the metal, namely, about 655° Cent. or 1,210° Fahr. As the specific heat of Al. is high, a large amount of heat is required to melt it, but a high temperature has to be avoided, hence the reason why the melting process is prolonged. It takes from thirty to fifty minutes to melt a charge from a cold crucible.

The casting of aluminium requires several precautions that have no place in brass, or iron casting. The "dead melting" of the latter must never be practised in Al. It is not only that the melting point is lower, being only 1,160° Fahr. or 626° Cent., but this temperature must not be much exceeded. A dark or dull red, barely visible in daylight, represents the proper temperature. Also the metal must not be put into the crucible, or the reverberatory furnace all at once, but dropped in in small portions at a time, as the portions previously introduced have melted, so delaying instead of hastening the melting process. The pieces are dipped in benzole before being put into the melting pot, or furnace. If metal is allowed to become overheated, it must be left to cool down before pouring. It will then be quite able to fill the smallest section, differing thus in a very marked manner from iron and brass. When the metal is all melted, it is stirred, and skimmed. It is then allowed to cool again previous to pouring.

Another thing is, that no flux is used, the reason being that if added it would cause the molten metal to take up silicon from the sides of the crucible. With a view to prevent risk of this, crucibles are properly lined with carbon, mixed with tar, or an oxide. Lampblack mixed with molasses makes a suitable lining, if dried on for several days slowly at a moderate temperature.

The methods of moulding differ also from those adopted in other metals. The shrinkage of Al. is about equal to that of brass, and steel, and for that reason larger runners are used than for iron, resembling those for steel, in dimensions. The metal is poured quickly in green sand moulds, and being at a low temperature, it soon sets. Moulds are rammed loosely, and vented very freely. In dry sand the metal is used hotter than for green, and is poured more slowly.

An important difference between the casting of aluminium and iron, or brass, lies in the ingates or runners used. These are of larger dimensions than those of the latter metal, and alloy, to permit them to act as feeders to the castings during shrinkage. They therefore fulfil the same function as head metal in steam, and hydraulic cylinders. A device often adopted resembles one used by iron-moulders, in stopping a pouring basin temporarily with a clay plug, and for a similar reason, to prevent the entrance of dross. A runner box is set over the mould of the casting, provided with holes in the bottom corresponding with the

ingates to the mould. These holes are closed with iron plugs until the runner box is filled with metal. The plugs are then removed, allowing the metal to run into the gates, leaving the scum in the box. Large risers are also necessary, and ample venting.

The lightness of aluminium has been utilised in keeping down weight on torpedo boats, and steam launches, and by substituting the metal for iron or steel in bed-plates for engines. Though excellent for the latter purpose, it has not yet been so successful in the construction of the hulls of yachts and torpedo boats as to induce its general employment therein, since it is subject to corrosion by sea water.

Aluminium can be stamped into forgings under the drop hammer, either hot or cold, and under the fly-press into vessels. It can be spun, the solution used being one comprising four parts of turpentine to one of stearic acid. It can be worked cold in sheets similarly to copper; polished, burnished, electro-plated, and soldered.

Aluminium, after casting, can be treated by forging, but as in steel ingots, all imperfections must be cut off first. These take the form of draws, spongy metal, and liquations. The metal must also be very pure. If it contains silicon or iron in any quantity, it will not forge well. With regard to heat, forging hot greatly diminishes its strength, while cold forging hardens it, and increases its tensile strength. If great hardness is required, forging must be done cold. The best average temperature to adopt is that at which a stick of hard wood smokes when pressed against the metal. Aluminium is hardened by hammering, rolling, and drawing.

When aluminium is intended for rolling, the slabs or ingots must be cast in closed ingot moulds, the metal faces of which are machined perfectly smooth, the reason for which is to make rolling easier, and to prevent spots appearing on the sheets. The internal faces of the moulds are coated with graphite and water; they must be hot, and the ingots cooled quickly in cold water to render them soft. No lubricant is used when rolling, and frequent annealing is necessary at a low red heat, just visible in the dark.

To obtain the cost of Al. sheet, relatively to that of copper, brass, steel, and tin, multiply the cost per pound of the copper sheet by 3·3, of the brass by 3·1, of the steel by 2·9, and of the tin by 2·8.

In the turnery and in the machine shop, aluminium is worked by light cuts and high speeds, lubricating with turpentine, benzine, or petroleum. This lessens the liability of the metal to tear out under the cutting. Aluminium can be easily sawn with a circular or band saw, using turpentine or other lubricant. Filing is best done with single-cut files, as being less liable to choke than cross-cut ones. It can be stamped, or pressed, either hot or cold, either dry, or with soap and water for heavy work, or with tallow for small articles. It is frosted by dropping for a few seconds in a hot 10 per cent. solution of caustic soda, containing about 2½ per cent. of common salt, till the surface turns black. It is then brushed in cold water and dipped in strong nitric acid till the metal becomes white again, when it is washed, and dried in sawdust. Aluminium is polished with a mixture of olive oil and rum, or of emery and tallow, followed by rouge and turpentine. It is burnished with bloodstone or with steel dipped in rum and oil, or in a solution of borax containing a little ammonia. Aluminium is engraved by protecting the plate with stearic acid and turpentine, or with rum and oil to prevent the graver from slipping.

The energetic oxidation of aluminium has been utilised in association with other metallic oxides, sulphides, and chlorides to effect the reduction of metals with which oxygen, sulphur, or chlorine combine. By this means welding operations otherwise difficult or impracticable are being regularly carried out. The identity of this Al. mixture is disguised under the name **Thermit**.

Aluminium is rolled regularly to $\frac{1}{1000}$ inch in thickness, and it can be afterwards beaten out into leaf. The metal for rolling is first cast in sheets from 1 inch to 1½ inches thick, in hot ingot moulds of iron, brushed with graphite diluted in water. It is necessary to anneal between each pass until the last few passes. Oil must not be used on the rolls. The heat for annealing plates must not exceed a low red. For sheets it must be much lower. Plates are

allowed to cool slowly, but sheets are dropped into cold running water, which softens them more effectually. As the reduction proceeds, the temperature for annealing is reduced until sheets under 25 B.W.G. can be heated in boiling water and cooled down in it. Drawing must be done very gradually with frequent heatings.

Aluminium is of great use in iron and steel founding, being added in small proportions to iron or steel in the ladle. It does not combine with these metals, but acts as a liberator of the contained gases, and delays the solidification of the metal, so giving the gases longer time to escape.

Aluminium Alloys.—Pure aluminium is of less value than its alloys. It has but a low tensile and compressive strength, and it is soft, and though suitable enough for culinary utensils, and such-like articles, its utilities are too limited for most castings without some hardening alloy. Yet its lightness renders it of unique value in many castings and forgings where it is desirable to keep weight down. In others, too, which are subject to little or no particular strains, it is of value. On the other hand, pure aluminium resists corrosion better than its alloys.

The principal metals which have been used in alloying aluminium are copper, zinc, nickel, titanium, tungsten, chromium, magnesium, silver, and manganese. The best quality of aluminium should be used for alloys, containing a percentage of pure metal not less than 99·5 or 99·75 per cent. In the case of those alloys where the added metal has a very high melting point, an alloy of the latter with a portion of aluminium is first made, and ingoted, and then added to the pure aluminium, in the same way that "temper" is added by brassfounders.

The commercial binary alloys of aluminium are divisible under two heads—the light alloys, containing from 90 to 99 per cent. of aluminium, with from 10 to 1 per cent. or less of another metal or metals; and the heavy alloys, which contain from 1 to 10 per cent. of aluminium, with from 99 to 90 per cent. of other metal or metals.

From this point of view some of the light alloys are not far removed from the pure metal. An alloy, though not so termed, comprising from 98·5 to 98·8 per cent. of pure aluminium, is better than a metal of 99·6 per cent. purity. The heavy alloys include the bronzes.

If 2 per cent. of titanium is mixed with aluminium, an alloy is produced having a tensile strength of from 30,000 to 35,000 lb. when rolled hard, and 21,000 lb. when annealed. An analysis of Wolframinium shows the presence of tungsten, thus:—Aluminium, 98·04 per cent.; copper, 0·375 per cent.; tin, 0·105 per cent.; antimony, 1·422 per cent.; and tungsten, 0·038. The copper imparts strength, the tin fusibility. Wolframinium has the colour of silver, and casts well in chilled or sand moulds. Dr Richards gives its strength as follows:—If hard rolled, it has a tensile strength of 52,000 lb. per square inch, with an elongation of 2·14 per cent.; if annealed, a strength of 38,000 lb., and an elongation of 15·24 per cent. Mannesmann found that an addition of a fraction of 1 per cent. of tungsten made an Al. alloy stronger, and increased its resistance to corrosion.

An alloy of aluminium with 10 per cent. of tin is whiter than aluminium, and is more easily soldered than the pure metal. Romanium is an alloy of wolfram, nickel and aluminium. Its tensile strength is about equal to that of Wolframinium, but it is much harder and of greater elasticity. Its special utilities lie in large castings, plates, and angle bars for machinery and in shipbuilding. The cheapest alloying element is zinc, and the zinc alloys happen to be nearly equal in mechanical properties to those made with more expensive metals.

One of the latest alloys of aluminium is that patented by Dr Ludwig Mach, in which magnesium is the single alloying element to the exclusion of others, as zinc, tin, bismuth, &c.; and magnalium the name of the alloy, which is lighter than Al., having a density of from 2·4 to 2·57. Experiments were conducted on proportions varying from 78 to 90 parts of aluminium and 2 to 30 parts of magnesium. The best mixture for castings has from 10 to 15 per cent. of magnesium. It remains hot for a long time, fills the most delicate moulds, the castings are bright, and sharp screw threads can be cut in them. The following table gives the principal results of alloying with magnesium:—

Two per cent. of Magnesium in Alloy.

	Tensile Strength per Square Inch. lb.	Elongation per cent.
Cast in sand - -	17,900	3·00
Cast in chills - -	28,600	2·00
Castings, water-chilled	40,000	1·00
Annealed sheet - -	25,600	18·00
Hard sheet - -	41,300	2·70
Four per cent. of Magnesium in Alloy.		
Cast in chills - -	28,600	2·00
Annealed sheet - -	28,200	8·00
Hard sheet - -	44,900	2·10
Six per cent. of Magnesium in Alloy.		
Castings, water-chilled	57,600	1·00
Annealed sheet - -	28,100	17·00
Hard sheet - -	44,100	1·00
Eight per cent. of Magnesium in Alloy.		
Castings, water-chilled	54,900	1·60
Ten per cent. of Magnesium in Alloy.		
Cast in sand - -	21,400	2·40
Cast in chills - -	33,600	3·40
Castings, water-chilled	61,100	4·20

See **Magnalium** for particulars of the commercial alloy.

Two recent alloys of aluminium are termed zisium and ziskon. Their chief value lies in castings, ziskon being the more rigid of the two. They can be cast extremely thin, and clean. Zisium has a breaking strength of about 4·9 tons per square inch, with an elongation of from 1 to 1·3 per cent. in 6 inches, and ziskon has a strength of about 11 tons per square inch, with an elongation of only 0;7 inch in 6 inches. The latter has a specific gravity of 3·35, that of zisium being 2·95. Both are silvery-white in colour, take a high polish, and both can be machined dry, like brass. Very sharp screw threads can be cut in them both. These alloys are manufactured by Carl Zeiss, of Jena.

The value of ferro-aluminium lies in the property which it possesses of keeping iron and steel fluid in the ladle, acting thus as a cleanser. It does not form an alloy with the casting, but clears the metal by decomposing the occluded gas, producing a slag, and so lessens the risk of blowholes. The alloy is used as follows:—The portion required is heated to nearly a white heat and placed in the bottom of the ladle or crucible, and the molten metal introduced above it and thoroughly mixed with an iron rod for three or four minutes before pouring. The quantity required varies with different kinds and qualities of iron, and is determined by experiment and experience. If 2 lb. of aluminium per ton of iron were required, as the 10 per cent. ferro-aluminium alloy contains 1 per cent. of aluminium to 10 of iron, 2,240 lb. of metal would require 20 lb. of ferro-aluminium to amalgamate 2 lb. of aluminium with the gases. If it is required to alloy aluminium with iron, then larger quantities of alloy must be used, and weights be reckoned proportionately.

Ferro-aluminium containing 10 per cent. of aluminium is supplied in ingots divided in thirty-six cubes of about 1 lb. each.

Good ferro-aluminium has a white and rather crystalline fracture, if free from graphitic carbon and silicon, as it should be. The following is a good analysis, by Mr Bedford:—

	Per cent.
Metallic Iron - -	89·54
Aluminium - -	10·20
Carbon (combined) - -	0·10
Manganese - - -	0·10
Silicon - - -	0·06
Sulphur - - -	trace
Phosphorus - - -	trace

The value of aluminium for this purpose of reducing the occluded gases which produce blowholes in iron and steel can hardly be overrated. Various theories have been formulated to account for the evolution of gases in the heart of molten metal, often in very large quantities, but the fact is none the less troublesome. And although it is indisputable that aluminium (and also ferro-silicon) lessens or prevents the presence of blowholes, the explanations offered are not of the nature of demonstrations. The small additions made are not sufficient to form alloys. But the effect of such additions appears to be to stop the formation of carbon monoxide gas, and the ebullition in the metal resulting therefrom. Hence the theory that aluminium being more greedy for oxygen at high temperatures than iron is, forms a slag with the oxygen in the iron oxide. But this does not explain the effect of aluminium on occluded nitrogen and hydrogen, the manner of which is still speculative.

Aluminium Bronze.—There are several grades of bronzes supplied in ingots, slabs, or billets. The British Aluminium Co., Ltd., make the following:—

Bronze A.—10 per cent. of aluminium, 90 per cent. of copper; sp. gr., 7·65; tensile strength in castings, 30 tons per square inch; elongation in 4 inches, 22 per cent.; melting point, 956° Cent.

Bronze B.—7½ per cent. of aluminium, 90½ per cent. of copper, 2½ per cent. of silicon; sp. gr., 7·7; tensile strength, 27 tons per square inch; elongation in 4 inches, 42 to 48 per cent., being therefore very highly ductile. But if forged, rolled, or drawn, the tensile strength is increased to 35 tons per square inch, and the elongation lessened to 30 or 32 per cent. in 4 inches.

Bronze C.—5 per cent. of aluminium, 95 per cent. of copper; sp. gr., 8·21; tensile strength in castings, 25 tons per square inch; elongation in 4 inches, 50 to 60 per cent.

Bronze D.—2½ per cent. of aluminium, 97½ per cent. of copper; sp. gr., 8·31; tensile strength in castings, 20 tons per square inch; elongation in 4 inches, 40 per cent.

The general effect of increasing the proportion of aluminium to copper is to increase the tensile strength of the alloy, and to lessen the elongation and the specific gravity. Wolframinium contains Wolfram in addition to copper and aluminium. It is specially suitable for rolling or drawing. Its tensile strength cast in sand is 10 tons, rolled or drawn 20 to 22 tons. Its elongation is from 12 to 20 per cent.

Aluminium Patterns.—Aluminium is used to a considerable extent for the metal patterns attached to plates in moulding machines. The great advantage of its employment here is the lessening of weight, which permits of the substitution of the more durable and stable metal for the weaker wood, the form of which is liable to change. It also reduces the weight of the metal patterns by about two-thirds, when compared with white alloys, and with brass and iron. Further, it is less liable to fracture than iron, because thicknesses can be increased, still with a lessening of weight. It is also less likely to suffer distortion than patterns of white metal, because more rigid, a point of much advantage when selecting metal suitable for the flimsier class of patterns.

Another point in favour of patterns of this metal is that corrosion does not occur, as it does in iron, and which renders beeswaxing of the latter necessary. The surface of the metal grows smoother with long service, and only gets discoloured, which is of no consequence in the case of foundry patterns.

Aluminium Solders.—The difficulties in soldering aluminium have been considerable. The reason why it is so difficult to solder is that its great conductivity removes the heat from the solder rapidly. The following give the compositions of solders which have been employed:—

Aluminium 2·38, zinc 26·19, tin 71·19, phosphorus, 0·24.

Aluminium 6, copper 4½, zinc 89½.

Aluminium 6, silver 3, copper 3, tin 18, zinc 9.

Bismuth 6, tin 94.

Tin 80, and zinc 20 parts, fluxed with a composition of stearic acid 80, tin chloride 10, and zinc chloride 10.

Another is composed of tin 20 parts, zinc 11 parts, aluminium 1 part, and phosphor tin 10 per cent.

The soldering bit should be of pure nickel, because copper causes discoloration. The aluminium must be heated first, or kept hot with a blow-pipe.

Aluminium Steel.—The effect of additions of aluminium to steel has been investigated by Mr Hadfield. He found that aluminium does not much affect the hardness of steel. One result is that it increases the size and coarseness of the grain of cast steel, particularly when 5 per cent. or more is added. When added up to about 0·5 per cent. it makes the fluid steel thick, so that it sets quickly. Aluminium added up to about 0·85 per cent. causes cast steel if annealed to stand bending double, cold. But further additions reduce the toughness.

In forged aluminium-steel, malleability is reduced by large additions of the metal. Up to 2·24 per cent. only the samples which were annealed bent double cold. Aluminium-steel does not therefore promise to become a rival to its nearest alloys, silicon and manganese steels, which are cheaper.

Amalgam.—An alloy in which mercury is one of the combining metals. An amalgam may be either solid or liquid, depending apparently on the quantity of mercury. The solid amalgams are regarded as definite compounds; the liquid amalgams are generally looked on as solutions of compounds in excess of mercury. The most important combinations are those with gold, silver, tin and sodium. With gold and silver, mercury readily combines at ordinary temperatures, a fact that was discovered in the middle of the sixteenth century, and which has been taken advantage of in the extraction of these metals from their ores ever since. The quartz is crushed, mixed with mercury, and placed in a revolving chamber. The mercury then extracts and combines with the gold present, forming a semi-fluid substance. The mercury is next driven off, leaving the gold behind. The ease with which mercury combines with the precious metals and allows itself to be subsequently driven off by heat, has resulted in an extensive use of this process in various arts; in gilding and plating, silvering mirrors, &c. Some metals, as antimony, will only amalgamate with heat, others like iron, cold.

Amalgamation for Gold and Silver.—Amalgamation is one of the processes by which the metallic gold and silver are separated from the gangue or dross with which they are mixed in the ore. The metals, nearly all of them, occur in a very finely divided state, held in the interstices of the rocks forming the ore. They also occur mixed with sulphides and other compounds of other metals. In both cases the ore is ground to a very fine powder, with the aid of water, and the slimes, as the wet powder is called, are passed over amalgamating plates, and where the compounds of other metals are present, through amalgamating pans. The object in both cases is to divide the gold, or the silver, from the dirt in which it is held, by the aid of the property possessed by mercury, of forming with all metals what is termed an amalgam. The amalgam formed with the gold or the silver is roasted in a furnace at a temperature at which the mercury is driven off as a vapour, it being afterwards condensed and used over again, the gold or silver remaining being melted into ingots in the usual way.

The amalgamating plates are fixed in the mortar boxes of the mill stamps, and immediately outside. They consist of plates of the purest and softest copper obtainable. The plates are of the same width as the mortar box of the stamp, and from 8 ft. to 12 ft. long, the length being measured in the direction in which the slimes flow. The amalgamated plates are intended to catch, as far as possible, all the free gold or silver, all that is present in the form of minute granules of the metal; and they are fixed at the point where the slimes are first made.

The ore is usually crushed to a certain size, by rock crushers of different forms, and is then milled, as it is called, crushed to a fine powder by the action of a battery of heavy stamps. The stamps are heavy pieces of iron attached to vertical stems working in guides, and arranged to rise and fall a certain number of times a minute. The stamp head falls on to a die in a mortar box, and the slimes pass out through a screen on to the amalgamating plates. The plates are usually inclined at a gentle angle, and are occasionally in a series of steps. The inclination depends upon the character of the gangue, or dirt. Copper plates that have the shiny surface given by rolling after the last annealing should not be used, as they will not take up the mercury properly. It will be understood that the copper plates are amalgamated, the mercury combining with the copper, and the gold, when it arrives, forms its own amalgam with the mercury lying on the surface of the copper plate. There is always a small quantity of free mercury present, with which the gold combines, but it will not lie on the copper plate, spread out in the form in which it is wanted, unless the copper plate has its whole surface thoroughly impregnated with mercury.

The copper plates have to be very carefully cleaned, before the mercury will take. The process is very similar to that of amalgamating zinc for use in galvanic batteries, and to the preparation of articles for electro-plating. The surface of the copper must be clean in the *chemical* sense. All dirt must be removed, and

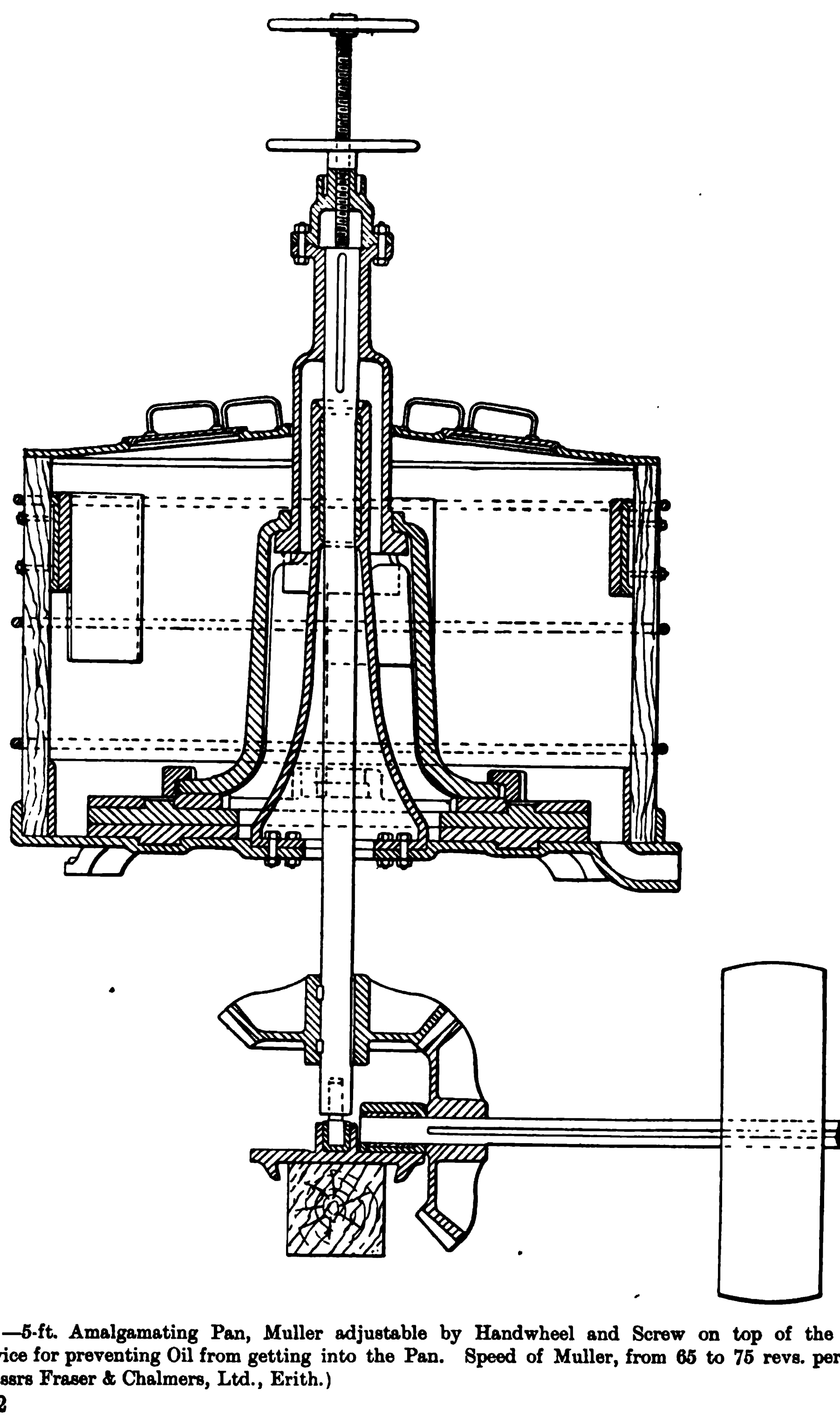


Fig. 55.—5-ft. Amalgamating Pan, Muller adjustable by Handwheel and Screw on top of the Spindle. Device for preventing Oil from getting into the Pan. Speed of Muller, from 65 to 75 revs. per minute. (Messrs Fraser & Chalmers, Ltd., Erith.)

also the layer of air that is always present, before the mercury will take. The copper plates are scrubbed with brushes, fine sand and water, assisted by solutions of caustic potash, and of cyanide of potassium. These plates must be quite flat, and their surfaces quite true, and they are therefore trued up with a hammer, and wood block, *in situ*. Care is necessary in using cyanide of potassium, as it is a poison, popularly known as prussic acid. Care is also necessary in using caustic soda solutions, as though they are not dangerous in the sense that cyanide of potassium is, they make the hands very uncomfortable. A little very weak acid is a good thing for the hands after using caustic potash.

Amalgamating Pans.—In amalgamating pans, the process of grinding and amalgamating goes on together. The object to be attained is the reduction of the ore to an impalpable powder, and the mixing of a certain quantity of mercury with the powder, so that the minute granules of gold or silver may find mercury adjacent, and combine with it. The process is employed for those ores in which the gold and silver is combined with the compounds of other metals, the very fine grinding enabling the mercury to penetrate to the fine granules of the metals, no matter how deeply they may be hidden among the gangue.

The amalgamating pan varies in form, but the usual pattern is a cylindrical tub, having a cast-iron bottom, and wooden sides. An example is given in Fig. 55. On the bottom of the pans there are cast-iron dies, somewhat similar to the cast-iron dies on which the iron stamp head falls within the mortar box, though of different shape and strength. They have the same object, the presentation of a hard surface against which the grinding, or hammering may go on. Above the dies is another apparatus, called the muller, that takes the place of the stamp head in the stamp mill, and which is practically an iron plate arranged to run over the die mentioned above, and to grind any substance that may be placed between them. The muller is of a special form, because it has to be driven in a special way, from below.

The amalgamating pan stands upon trestles, or any convenient support, to which pulleys, or any other power agency, can be attached, and the muller is driven by a shaft passing vertically through the centre of the pan. It is a casting the members of which are nearly at right angles to each other, one arranged radially to the pan, and the other nearly parallel to the axis. It is the vertical member which receives the power from the vertical driving spindle. There is an arrangement also by which the muller can be raised or lowered, to press it closer to the die, or the reverse, as required by the nature of the ore being dealt with.

The ore is passed into the amalgamating pans from the concentrating machinery, mercury is added, steam applied, either in the pan, or in a steam box underneath, and the mass is ground up together. The ground pulp passes from the pans to settling tanks, *see* Fig. 56, where the amalgam of gold, or silver, and mercury, is separated from the dirt by gravitation, water being added to assist the process, the pulp being run off gradually at different levels until the amalgam is left by itself, when it is taken to the roasting furnaces, and treated in a similar manner to that taken from the amalgamating plates.

As there is often a waste of mercury by fine globules being carried off with the dirt, or pulp, as it drains away from the amalgam, a further apparatus is sometimes provided, consisting of another tub in which an agitator is fixed. The agitator consists of two or more arms arranged diametrally across the top of the tub, and carrying vertical stirrers, the whole being revolved in the pulpy mass. The globules of mercury are separated, and the residue is treated over again in the amalgamating pan, if it is considered worth the expense. The final refuse is sometimes treated to a further amalgamation in what is called the clean-up pan, an apparatus similar to the amalgamating pan, but with wooden shoes instead of iron. Fresh mercury is added, the whole being ground up together as before.

There is a considerable waste of mercury in the amalgamation process, no matter how carefully it may be carried out. Mercury has to be added constantly to the amalgamating

plates to keep them going, to make up for that taken up by the gold, and the whole of the mercury thus appropriated by the gold is not recovered. There is a waste of mercury in the amalgamating pans owing to the mercury being drawn over with the pulp as described, and there is a more or less continuous waste at every step, on account of the fact that mercury has the peculiar properties so well known. All of these things have to be taken into account when estimating the cost of running a gold or silver reduction plant.

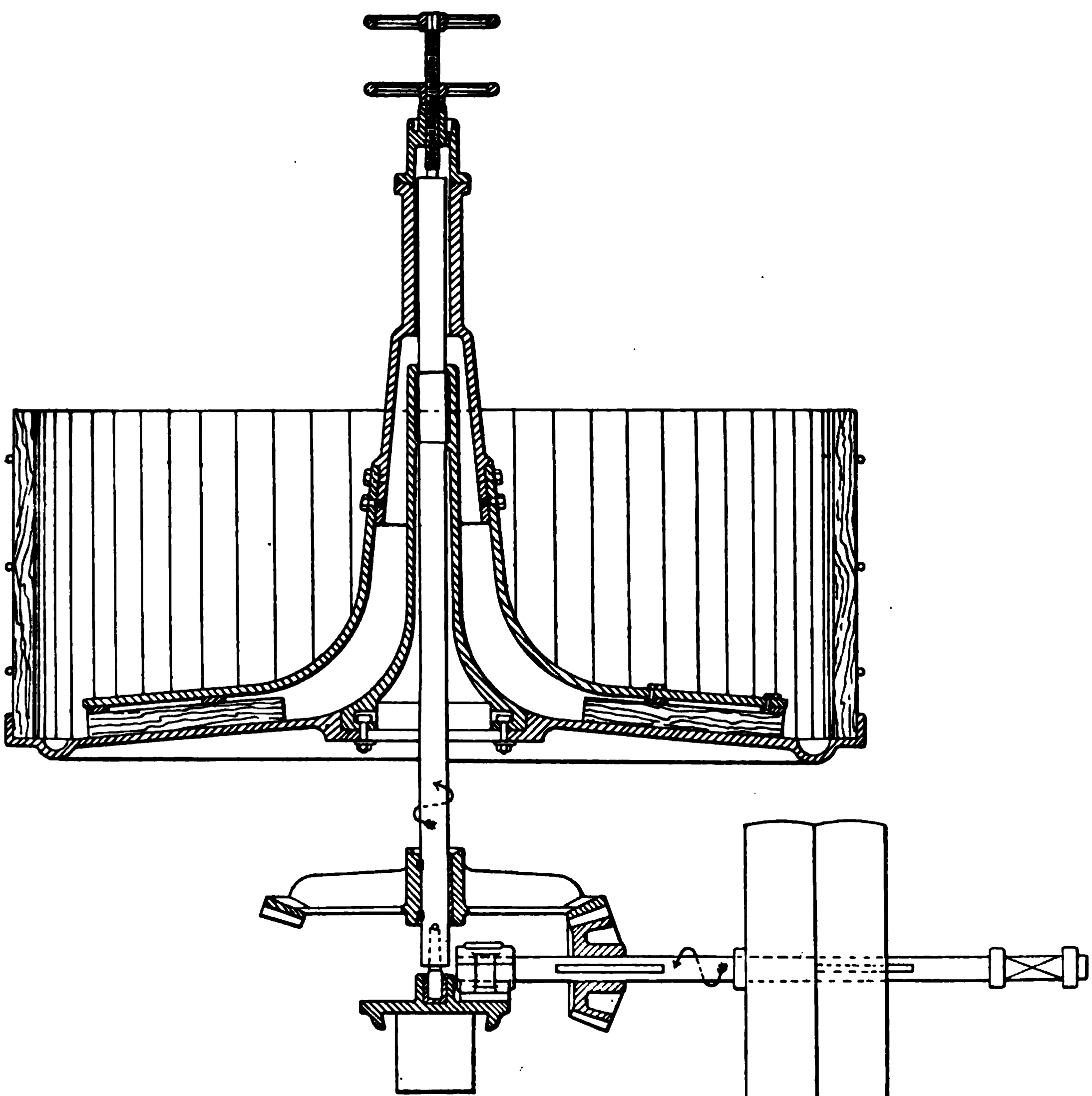


Fig. 56.—8-ft. Settler or Settling Pan. Speed of Muller, 12 to 16 revs. per minute. (Fraser & Chalmers, Ltd.)

Ammeter or **Ampèremeter.**—The ammeter is the apparatus used for measuring the strength of the electric current, in ampères, passing in any electric circuit. The instrument must be connected *in* the circuit, in such a manner that the whole of the current to be measured passes through its coils.

In central generating stations, and under

similar conditions, there are generally several ammeters in use—one to measure the whole current passing out of the station, and others to measure the currents being generated by each dynamo, and being delivered to each feeder. The construction of the apparatus varies very considerably, but all forms are on certain main lines. There is always a copper conductor, through which the current to be measured passes, the size of the conductor varying from a very fine wire, used to measure a current of a few milliampères (thousandths of an ampère), up to substantial strips, or spirals of copper used to measure currents of several thousands of ampères. The insulation of the conductor used in the ammeter need not be high. With very small currents, it may be silk, or cotton, sufficient to prevent contact between the successive turns of the coil into which the conductor is formed. With the larger instruments, those measuring several hundreds, or thousands of ampères, the insulation will only be the air space between the successive turns of the spiral.

In all ammeters there is a dial, graduated for the range of current the instrument is to measure. No instrument has yet been made that will read from milliampères to thousands of ampères, and the majority of ammeters are constructed to read over a very limited range, as by this arrangement, a larger space can be devoted to a given difference in quantity. It will be easily understood that an ammeter constructed to read in thousands of ampères will make no sign with a good many milliampères, nor even with ampères, and very little with hundreds of ampères. On the other hand, if very much larger currents are allowed to pass, or are forced through ammeters than they are constructed to measure, the results may be disastrous, on account of the heat that will be generated by the large currents. Where the conductor is insulated with cotton, or silk, these substances will be burnt, and the apparatus will afterwards read very much lower than it should do, because the current will not pass round all the turns of the conductor, and will consequently not exert the force upon the portion of the apparatus actuating the pointer, that it was intended to.

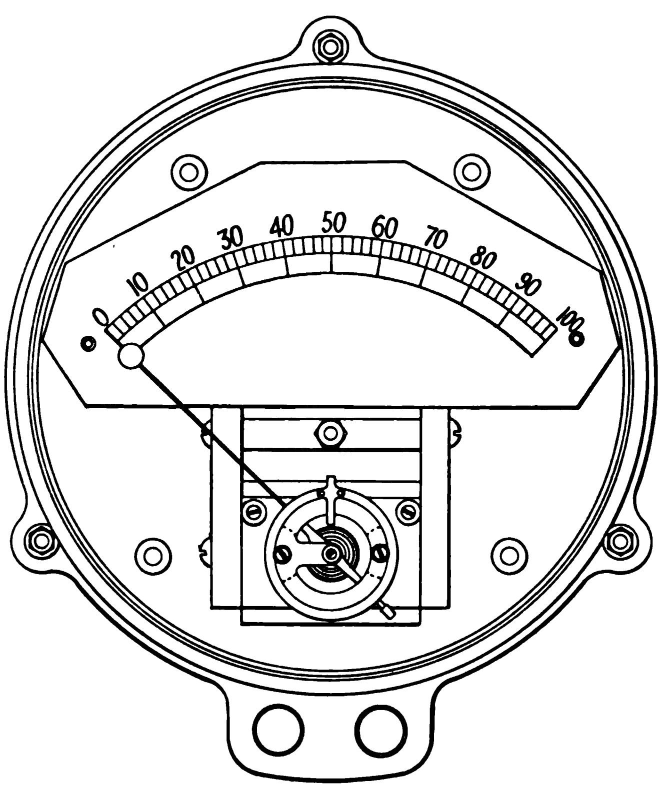
The arrangement of the dial varies. With ammeters designed for circuits where reversal of the currents may be expected, the dial is arranged so that the pointer moves to the right, or the left of a zero line, according as the current is in one, or the other direction. In the great majority of ammeters, however, the pointer moves only in one direction, from a zero on the left, along a scale formed on the arc of a circle. The graduation of the scale over which the pointer moves, varies also. As each instrument is designed for currents of a particular range, it usually follows that the makers give the part of the scale where the pointer will be for the greater part of its working life, a larger space than the others. Usually also the early part of the scale, except in very low reading instruments, is made very small, the practical readings of the instrument commencing near where the needle will usually be when it is in use. The pointer of the ammeter, it will be understood, moves over the graduated scale, in obedience to the pull exerted by the current passing in the conductor referred to above, and the methods of arranging this pull are again various. All ammeters have been developed from the older instrument known as the galvanometer, in which a coil of wire surrounded a needle magnet, the needle being deflected out of the magnetic meridian, by the force exerted by the current passing in the coils.

In the first instruments that were placed upon the market, in the early days of electric lighting, this arrangement was followed rather closely, there being a needle magnet actuating the pointer, the needle itself being pivoted inside a coil of wire, which again was placed in a very powerful magnetic field. The current passing in the coils had to overcome the force of the magnetic field, and the amount by which the needle was deflected, and the pointer with it, measured the strength of the current passing, the force exerted by the magnet bringing the needle back to zero, when the current ceased to pass. The powerful magnetic field was created by a horse-shoe magnet, whose poles closely embraced the coil. In a modification of this which finds much favour, at the present day, there is again a magnet creating a powerful magnetic field, and the coil in which the current

is passing moves within the field, when caused to do so by the action of the current passing, the motion of the coil and the pointer with it registering the current passing in the coil (*see* Figs. 57 and 58).

In these instruments, the spaces moved over by the pointer, for successive increments of current, are not necessarily equal, usually they vary with the position of the coil, but they should be the same, in any instrument, for the same current. All instruments are calibrated at the factory, or elsewhere, by comparison with a standard instrument, kept for the purpose, whose own calibration is carefully checked frequently.

In yet another class of instrument, which has also found much favour, there is merely a circular coil of wire, or a conductor arranged in a circular form, and a curved piece of iron or mild steel is pivoted within the coil and maintained when at rest, in a certain position, by the force of gravity. When a current passes in the coil, the piece of iron moves away from its position, in its endeavour to reach the strongest part of the field, and carries a pointer with it, moving over a graduated scale as in the other cases. And yet another arrangement consists of two coils, one moving, and one stationary, the moving coil carrying the pointer, as before.



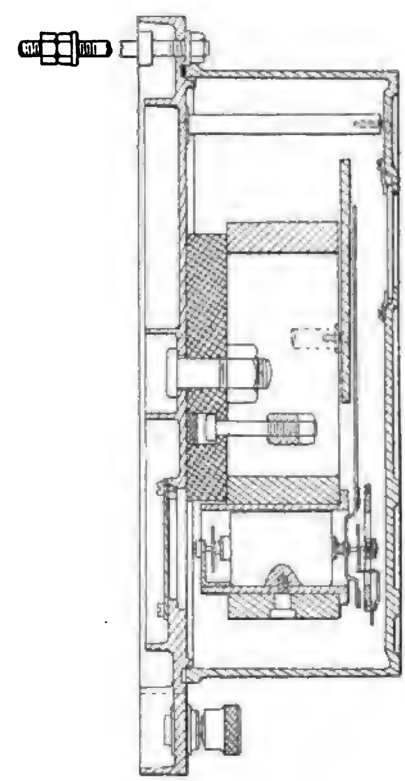


Fig. 57.
Plan of Arrangement of Ferranti Moving Coil Ammeter.

Sectional Elevation of the same.

There are also modifications of the above, such as a hollow coil of wire, with a crescent-shaped piece of iron partly entered into its mouth, the iron being drawn more and more into the coil, as the current passing increases in strength. There are also apparatus where the magnet is entirely dispensed with, in which heat generated by the current in the coil either moves a column of liquid, or compresses a column of air,—or elongates a wire, that is stretched by

a spring, a needle pointer moving up a vertical scale or over a dial as the current strength increases.

The shape again of the ammeter varies. The favourite form is a cylindrical brass, or iron case, with a glass circular face, having a card, or enamelled disc underneath, with the scale occupying a portion of its surface. In other forms the instrument takes the form of a sector of a circle, the scale occupying the arc on its periphery, and in again another set of apparatus, the instrument is turned with its edge towards the observer, the scale being set on the edge of a sector of a circle, so that a number can be fixed at the top of a switchboard, without occupying too much space. The solenoid electro-magnet has been used occasionally, the exciting coil of the magnet carrying the current to be measured, and the current strength being indicated by the pull exerted upon the iron core, as shown by a needle either moving vertically, or over a circle.

Ammeters for alternate currents are constructed very much on the same lines as for continuous currents, but they must be specially graduated for every periodicity, each number of alternations per second; and permanent needle magnets cannot be used, as the successive currents quickly following each other would neutralise each other's effect.

Ammonia. — Ammonia is a chemical compound of nitrogen and hydrogen gases, its chemical formula being NH_3. That is to say, one atom of nitrogen is combined with three atoms of hydrogen to form two atoms, or one molecule of ammonia. In terms of weight, 14 parts by weight of nitrogen combine with 3 parts by weight of hydrogen. Ammonia exists as a gas under ordinary temperatures and pressures, but it becomes liquid at $-30°$ Fahr. at the ordinary pressure of the atmosphere, and at higher temperatures if higher pressures are employed. At a temperature of 900° Fahr. ammonia breaks up into its constituent gases. Partial decomposition is stated to take place at lower temperatures under certain conditions. Anhydrous ammonia, the pure gas, dissolves in water, in different proportions, according to the temperature of the water. At 32° Fahr. 1 lb. of water will dissolve 0·899 lb. ammonia, at 50° Fahr. 0·684 lb., at 86° Fahr. 0·408 lb., at 122° Fahr. 0·284 lb., at 140° Fahr. 0·238 lb., at 176° Fahr. 0·154 lb., at 212° Fahr. (the boiling point of water) 0·074 lb. The above figures are of great importance, as upon them depends one form of refrigerating apparatus, in which ammonia is used. It will be seen that while at the freezing point of water, 1 lb. of water dissolves nearly 1 lb. of ammonia, at the boiling point of water it will only dissolve a very small fraction of 1 lb.

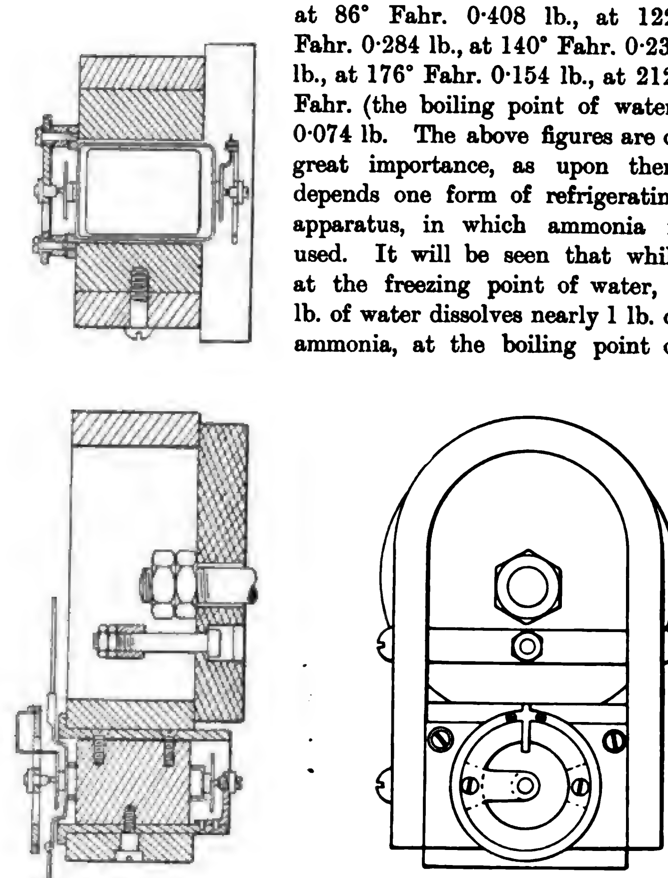


Fig. 58.—Details of Arrangement of Ferranti Ammeter.

Ammonia is used in refrigerating apparatus, in both the absorption and compression systems, the ammonia being caused to alternately assume the liquid and gaseous form, the heat to enable it to pass from the liquid to the gaseous state being taken from the substances that are to be cooled. The latent heat of ammonia gas is

555·5 B.Th. Units at 0° Fahr. That is, every pound of ammonia requires, and absorbs, 555·5 B.Th. Units in passing from the liquid to the gaseous condition at zero Fahrenheit.

In the compression system, the gas is compressed by mechanical power, and then passed through a condenser, where it assumes the liquid form, the latent heat of gasification having been carried off by the cooling water. In the absorption system the gas is dissolved in water and then driven off by the application of heat, the process of driving off compressing it, in a somewhat similar manner to the compression system. The gas is then cooled to the liquid form in the condenser, as with the compression system.

At 0° Fahr. ammonia exerts a pressure of 30 lb. per square inch, the volume of 1 lb. of the gas at that temperature is 9 cubic feet, and the weight of a cubic foot of the gas 0·11 lb. At 30° Fahr. its pressure is 59 lb. per square inch, its latent heat has sunk to 537 B.Th. Units, the volume of 1 lb. of the gas is 4·75 cubic feet, and the weight of a cubic foot of the gas 0·21 lb. At 150° Fahr. its latent heat has fallen to 458 B.Th. Units, the volume of 1 lb. is 0·7 cubic foot, and the weight of a cubic foot of the gas 1·44 lb., while its pressure is 450 lb. The specific heat of ammonia in the gaseous form is 0·508 at constant pressure, and 0·3913 at constant volume. The specific heat of liquefied ammonia is from 1 to 1·228.

When ammonia, in the gaseous form, is dissolved in water, heat is liberated, the gas assuming the liquid condition, and surrendering its latent heat of gasification to the solvent. When 1 lb. of ammonia gas is absorbed by a large quantity of water, 200 lb., or more, 925 B.Th. Units are liberated. The quantity of heat liberated when ammonia is dissolved in smaller quantities of water is given by the formula:—$Q = 925 - \frac{124}{n}$ Heat Units, where Q is the quantity of heat liberated in B.Th. Units, and n is the number of pounds of water to 1 lb. of ammonia. The heat liberated when ammonia is added to an aqueous solution of ammonia is found from the formula:—

$$Q_1 = 925b - \frac{142(2b + b_2)}{n}$$

where Q_1 is the quantity of heat liberated in B.Th. Units, and b is the number of pounds of ammonia added to a solution containing 1 lb. of ammonia to n lb. of water.

Tests for Ammonia.—The purity of anhydrous ammonia is tested with a thermometer, when the liquid is boiling. As it boils at −29° Fahr. when pure, if an accurate thermometer be inserted in the flask containing ammonia in the act of boiling, if the temperature differs materially from −29° Fahr. the material must be impure. In this test allowance must be made for the varying pressure of the atmosphere. If there is an oily or watery residue left, in a flask from which ammonia has been evaporated, the substance is impure. Leakages of ammonia are detected by the smell, and by the white fumes formed on a glass rod moistened with hydrochloric acid, held near. To detect ammonia in water or brine, Nessler's Reagent is employed, consisting of a solution of potassium iodide, potassium hydrate, and mercuric chloride, prepared in a special manner. A few drops of the resultant liquor of Nessler's Reagent, added to a solution in which ammonia is suspected, will cause a yellow or brown colouring if ammonia is present, yellow with small quantities, brown with larger.

The solubility of ammonia in water is affected by the pressure. With an absolute pressure of 14·67 lb., about the ordinary atmospheric pressure, 0·899 lb. of ammonia is dissolved in 1 lb. of water, at 32° Fahr. At a pressure of 36·67 lb. absolute, the quantity goes up to 2·07 lb. per pound of water with the same temperature. With a temperature of 68° Fahr., 1 lb. of water dissolves 0·518 lb. at 14·67 lb. absolute pressure, and 0·955 lb. at 36·67 lb. absolute pressure. With a temperature of 104° Fahr. the quantity goes up from 0·338 lb. with 14·67 lb. pressure to 0·58 with 36·67 lb. pressure. With a temperature of 212° Fahr. the quantity rises from 0·074 lb. at 14·67 lb. pressure to 0·135 lb. at 27 lb. pressure.

Ammonia Machinery for Refrigerating Purposes.—As indicated in the article on ammonia, it is used in both the absorption and compression systems. In both the following apparatus are common:—The condenser, where the hot gas is cooled, and liquefied; the evapo-

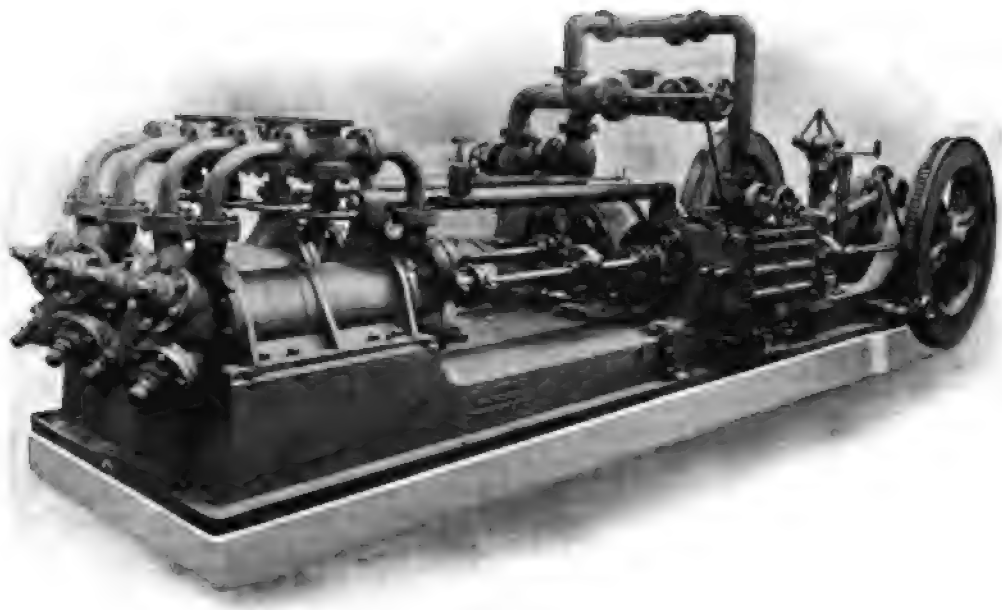


Fig. 59.—Double-acting Duplex Ammonia Compressor, directly driven by Duplex Compound Steam Engine. (Haslam Foundry & Engineering Co., Ltd.)

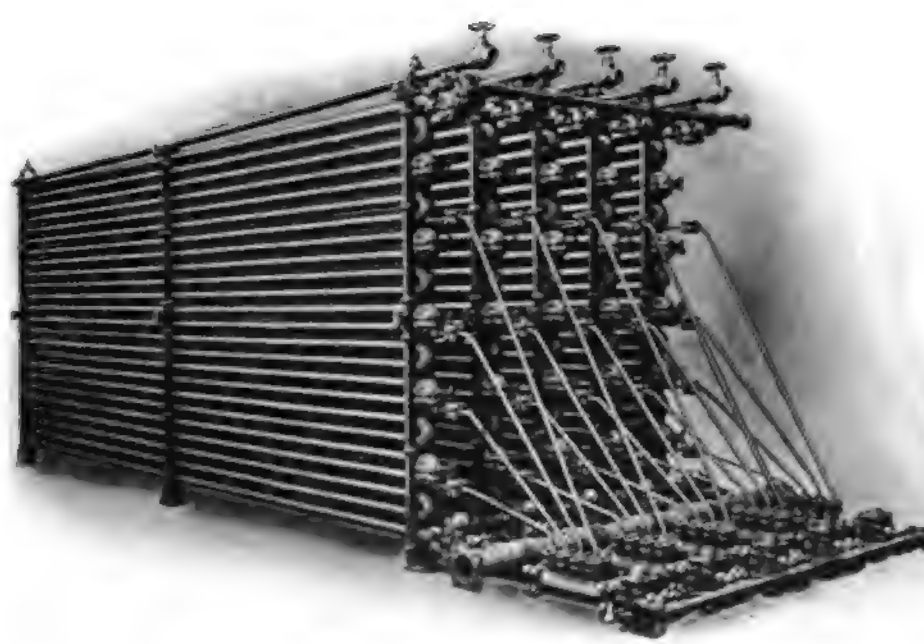


Fig. 61.—Atmospheric Condenser for Ammonia.
The hot compressed gas passes through the pipes, and water trickles down over them, the liquefied gas being drawn off as formed by the junction pipes shown on the right. (Haslam Foundry & Engineering Co., Ltd.)

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rator, where the liquid expands to the gaseous condition. Very frequently also there is a brine tank, where a solution of calcium chloride is cooled, the brine being used to cool the chambers in which produce is stored, or the water from which ice is being made.

The Refrigeration Circuit, with Compression.—The refrigeration circuit with the compression system, comprises the compressor, the condenser, and the evaporating coils. The compressor is a pump, which sucks in the gas that has done its work in the evaporator coils at each suction stroke, compresses it, and forces it on to the condenser at each compression stroke. Compressors are single-acting, or double-acting. Single-acting compressors only draw in gas on one side of the piston, compressing it, and expelling it, on the same side of the piston, by the return stroke. In double-acting compressors, Figs. 59, Plate III., and 60, the gas is drawn in on both sides of the piston, and expelled on both sides, the gas entering behind the piston which is compressing,—on the opposite side.

Lubrication is an important matter in connection with compressors, both of the piston and the bearings. For the latter, oil is maintained within the bearings under pressure from the cylinder itself, so that the ammonia shall not escape. In some forms of compressor oil is injected into the compressor cylinder, at a certain part of the stroke, to perform the double office of lubricating the piston, and to fill the clearance space at the end of the cylinder, so that ammonia may not be left there after the compression stroke, the oil being pumped out afterwards. In all ammonia compression systems, the ammonia is passed through an oil separator, after it leaves the compressor, before it is used again.

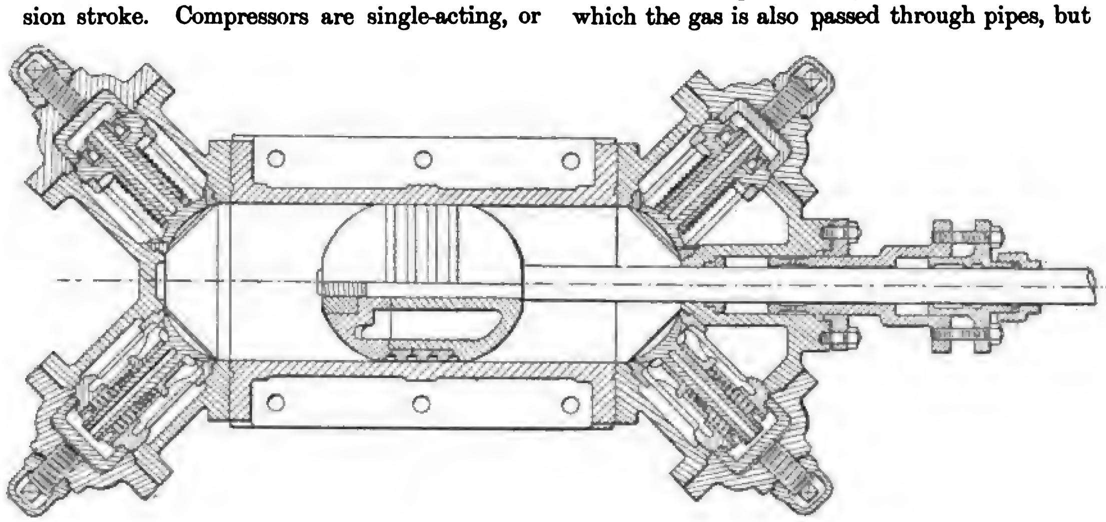

Fig. 60.—Double-Acting Haslam Ammonia Compression Cylinder, showing Suction and Delivery Valves at each end of the Cylinder, and Piston, with its Rod.

The Condenser.—The condenser is made in two forms—the submerged, in which the gas passes along pipes contained in a tank through which water is kept in continual circulation; and the atmospheric, Fig. 61, Plate III., in which the gas is also passed through pipes, but the pipes are exposed to the action of the atmosphere, water continually dripping down over them, and some of the water evaporating as it trickles. This method is very efficient in warm climates, as the hotter the air, the larger the quantity of watery vapour it can accommodate. It is also very efficient in windy situations.

The Evaporator, or Evaporating Coils.—These are coils of pipe, made in different forms, through which the liquefied gas passes, and in which it is allowed to assume the gaseous form. The passage of the liquefied ammonia into the pipes is controlled by an expansion cock, something on the lines of a stop valve with steam, but with special arrangements. Where brine is used, the expansion coils are immersed in a

tank through which the brine is kept in continual circulation, just as the water is with the submerged condenser; but the brine is brought back to the evaporating tank, after it has done its work in cooling the chamber.

Absorption Apparatus.—The absorption apparatus consists of a generator, an absorber, an analyser, a rectifier, and an exchanger, *see* Fig. 62, Plate IV. In the latest forms of absorption apparatus, all of the above take the form of iron, or steel cylinders, in which pipes are enclosed. In the generator, steam passes through the pipes, raising the temperature of the ammoniacal solution surrounding them, and driving off the ammonia. The analyser is usually contained in the generator, and consists of baffle plates, gratings, and similar arrangements, designed to throw back any watery vapour that may be driven off with the ammonia. The ebullition of the water containing the ammonia in solution carries over minute quantities of water with the ammonia, very much in the way that watery vapour is carried over with the steam in steam boilers. Causing the mixture to impinge on the baffles, gratings, &c., condenses a portion of the watery vapour, and it runs back into the generator. A further portion is condensed in the rectifier, where it is subjected to the cooling action of water running through the pipes referred to above. The mixture of gas and water vapour is cooled sufficiently to condense the water vapour, but not the ammonia gas. Next the gas passes through the condenser, and thence to the evaporating coils, as with the compression system.

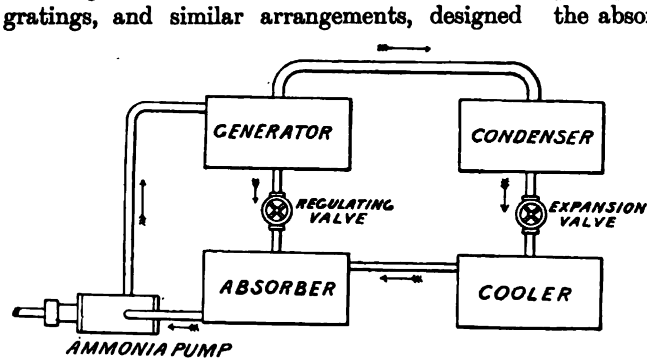

Fig. 63.—Diagram showing Arrangement of Ammonia Absorption Plant. The gas, it will be seen, passes from the generator to the condenser, then to the cooler (evaporator), then to the absorber, while there is an exchange of liquid between generator and absorber.

After passing through the evaporating coils, and performing its work there, the gas, as it has now again become, passes to the absorber, where it is again dissolved by water. There is a constant interchange between the generator and the absorber, of heat and liquid, *see* the diagram, Fig. 63. The generator requires as much heat as it can get; the absorber wants its temperature maintained as low as possible, in order that it may dissolve as much gas as possible. On the other hand, the solution of the gas in the water liberates heat. Further, there is considerable difference in the specific gravities of the strong and weak liquors. Advantage is taken of this latter fact, to cause a passage of weak liquor from the generator to the absorber, and of the stronger liquor, as it is formed, from the absorber to the generator. The two streams pass through the exchanger, in pipes arranged for the purpose, the liquor from the generator that is on its way to the absorber giving up some of its heat to the liquor from the absorber that is on its way to the generator. In addition, the liquor on its way to the absorber is cooled by the aid of water, running in pipes, as described. One lot of water is used for all the above, passing in succession through the different apparatus.

The absorption apparatus seems complicated, but in practice it is very simple. In the latest form the cylinders representing the different parts of the apparatus are mounted, two horizontally, side by side, and the remainder, one above the other vertically, the water and steam connections being easily made. A small pump for the ammonia, mounted on one of the cylinders, and fed with steam that has already done duty in the generator, completes the apparatus, except the evaporator, brine tank, &c.

Ammonia is used very largely for refrigeration, because its latent heat of evaporation is so much greater than that of the other agents employed. Care must be taken in handling the apparatus, as the fumes are poisonous if present in only a very small percentage. When an escape occurs, with ammonia, the ground is the safest

place, as the gas rises. Keep low, and dilute the gas with air, as quickly as possible. Ammonia does not explode, in the sense that petrol does, but if confined in a tank or other vessel, and subjected to great pressure, by heat, or from other causes, it may burst the vessel, with disastrous results.

Ammoniac—Sal.—*See* **Sal-Ammoniac.**

Ammunition.—*See* **Projectiles.**

Ammunition Hoist.—*See* **Hoists.**

Ampère.—The unit of strength of electric current. A pressure of one volt will force one ampère through a resistance of one ohm. If this current is maintained for one second, one unit of electrical quantity is delivered, called the coulomb. *See* **Electric Currents.**

Ampère Hour.—A convenient unit of electricity—the quantity of electricity delivered by a current of one ampère in one hour. *See* **Electric Currents.**

Ampère Meter.—*See* **Ammeter**, the abbreviated form now in use.

Analysis, Chemical.—Chemical analysis may be either qualitative or quantitative. By qualitative analysis the chemist determines what substances are present in a compound; by quantitative analysis the relative proportions, weights or volumes of these constituents are ascertained. The former process, for example, will demonstrate that CO_2 is composed of carbon and oxygen, while the latter process shows that these two elements exist in the proportion of 12 parts of carbon to $15{\cdot}96 \times 2$ or $31{\cdot}92$ parts of oxygen. When a compound substance is broken up into constituents which are themselves compounds we get an example of *proximate* analysis, while if these compounds are still further broken up into the elements composing them we speak of the process as *ultimate* analysis.

As regards the methods of analysis the examination may be by means of the blowpipe, or by the use of certain reagents for qualitative analysis, and by gravimetrical, volumetrical, or spectroscopic analysis for quantitative analysis. Substances tested by the blowpipe are heated on a piece of charcoal, on platinum wire, fused with potassium nitrate, and so on. Or, the substance may be dissolved in water or acid, and by the addition of certain reagents, certain precipitates are thrown down. For instance, when a white precipitate is thrown down on the addition of HCL to a solution it may be AgCL (argentic chloride), $PbCL_2$ (plumbic chloride), or Hg_2CL_2 (mercurous chloride). After precipitation the metal may be carefully weighed—a process termed gravimetrical analysis. Volumetrical analysis is concerned with the measure instead of the balance, and determines the amount of the constituents in a solution by the use of standard solutions of oxidising agents, acids, or alkalies, combined with colour tests to show when the action is complete. Finally, the spectroscope may be called into use. The metal is volatilised, and the spectrum obtained gives an indication of the metal or metals present.

Anastigmatic Lens.—This is the lens *par excellence* for the photography of machinery, machine tools, cranes, &c. It may be regarded as the ultimate development of the rapid rectilinear lens, and possesses in the highest degree three qualities essential in engineering photography—(*a*) Flatness of field; (*b*) extreme covering power; (*c*) perfect definition. Chromatic and spherical aberration, astigmatism, inequality of illumination, distortion, and limitation of angle of view are all reduced to the minimum in these excellent lenses, so that in combination with a camera possessing a liberal range of movements the anastigmatic lens may be relied on in the most difficult cases. Its weakest point is in the lack of depth of definition, which has to be sacrificed to secure such a high speed. This, however, is easily remedied by working with a small stop. Another valuable feature about this type of lens is that it can be used on a plate larger than it is intended to cover when worked at a small aperture. It thus makes a good wide angle lens for use in cramped, confined positions. On the other hand, symmetrical or universal anastigmatics, as they are called, allow of each combination being used separately as a long focus lens, a quality useful when it is required to photograph small details in a machine or structure.

Anchors.—In ancient times, the anchor consisted merely of a weight, such as a large stone, with some arrangement for attaching a hemp cable to it. Later came the anchor with one arm, and no stock; then the anchor with

two arms, with the ends of the arms spread out in the well-known form, called the flukes, to enable them to grip the ground better, and with a stock. The stock of the anchor that was used, up till very recently, is wrongly drawn in the pictures extant. The plane of the stock is at right angles to that of the arms. The old-time anchor consisted of a shank, with two arms, ending in flukes, as described above, with a shackle ring at the end of the shank furthest from the arms, and a stock of wood, bound with iron straps, clasping the shank just below the shackle. In small anchors the stock was also of iron, slipped into a hole in the shank. The object of the stock was, in case the anchor, as often happened, fell flat on the ground, the arms lying on the ground, in place of one of them sinking into it, the vessel would drag the anchor along the ground, and the stock, which would be nearly perpendicular to the ground, would cant the anchor over, till one of the flukes caught and sunk in.

The process of stowing one of the old anchors was somewhat cumbersome. After the anchor had been broken out of the ground, and had been hove up to the bows, a tackle called the cat, consisting of a huge block with three sheaves in it, and with an immense hook attached, was lowered so as to catch hold of the ring of the anchor. When the anchor was hooked, the cat was run away with, and the anchor run up to a short davit at the bows, called the cathead, where its ring was securely lashed, but with a tumbling arrangement that enabled it to be let go instantly when the sea-going lashings had been cast off. After the ring had been hove up to the cathead, another large block, with another large hook, was let down, the hook catching the outer fluke of the anchor. This tackle was called the fish, and the process was called fishing. The fluke of the anchor was hove up to the side of the ship, and rested lightly on a small sloping ledge provided for it, securely lashed there, also with a tumbling arrangement enabling it to be let go instantly. When the ship was about to anchor, the extra lashings were cleared away from the ring and the flukes, and two men stood ready, with ropes attached to levers working the tumblers of the cat and fish respectively. At a signal or order from the boatswain, both pulled their levers, and the anchor fell with a splash.

It will be seen that the old anchor occupied a good deal of space, and was sometimes a source of anxiety in rough weather, owing to the exposed position in which it was carried. The holding power of the anchor was also not always as great as an anxious captain would have liked.

The Stockless Anchor.—The modern anchor has no stock, and both flukes take part in holding the ship. In the stockless anchor, there is the shank, as before, but the arms do not form part of the same casting with the shank as in the old anchor. The two arms are in one casting, which is pivoted in the middle, in a place provided for it at the end of the shank. The arms stand at an acute angle with the shank, and the flukes are more or less pointed. As the anchor falls, the flukes sink into the ground, and grip a large portion, presenting a broad surface for the chain to pull against, the two flukes taking part in the operation, instead of only one as in the old form. If the anchor should fall on its side, the fluke on which it falls acts in the same way that the stock of the old anchor did, turning the anchor over, till the flukes sink in. There is no necessity for catting and fishing. When getting under weigh the anchor is run straight up to the bows, and the shank is entered into the hawse pipe, after the cable, the anchor being stowed snugly out of the way, and is yet in position for letting go quickly if required. In the old days, when "wooden walls" were England's defence, anchors of 5 tons were large, the largest ships rarely carrying heavier. Now anchors of 10 tons are common. In the old days, captains looked out to get plenty of room, when at anchor, so as to be able to pay out as much cable as possible; the object being to have much weight on the bottom, for the ship to pull against, and to have the pull against the anchor itself, at the best possible angle. The best angle would be a straight line, and the nearer the ship could get to that, the safer she was in case of bad weather. With the stockless anchor, a test was made on one of H.M. ships, at Spithead,

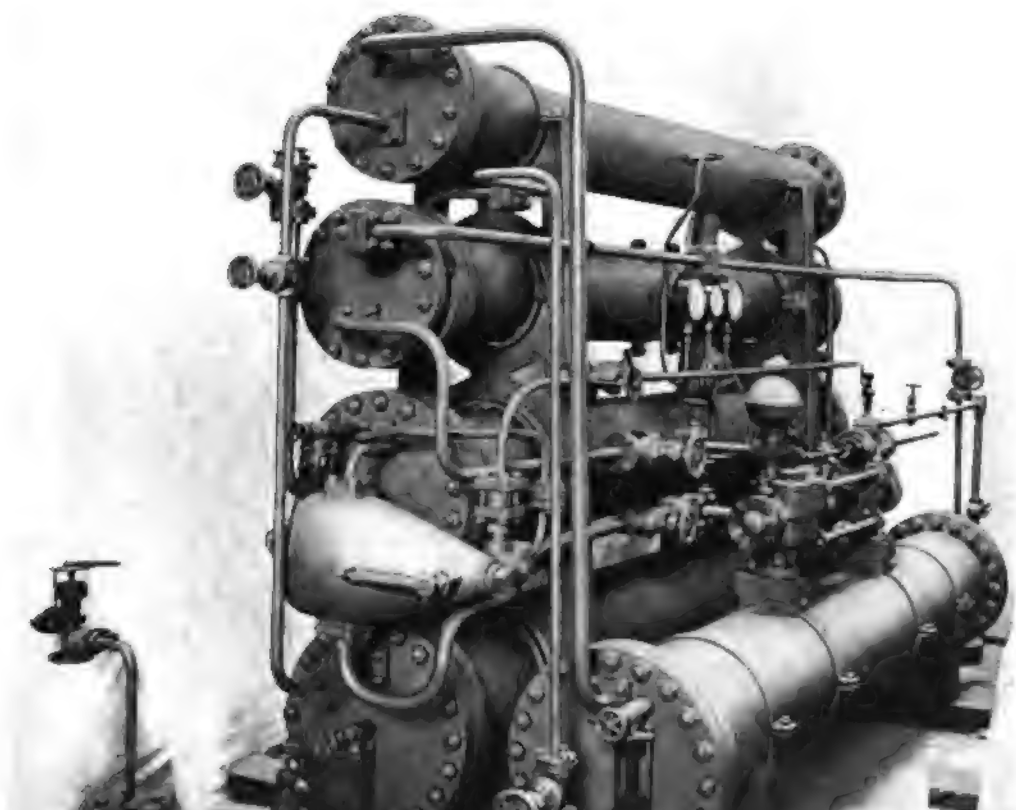

Fig. 62.—Ammonia Absorption Apparatus, comprising Generator, Absorber, Rectifier, Analyser, Exchanger, and Condenser. (Ransomes & Rapier, Ltd., Ipswich.)

To face page 112.

steaming against her anchors, with engines at full power, but the anchor is stated only to have moved slightly to get a better grip, and then resisted all efforts to pull it out. When getting up anchor, the ship is, of course, right over her anchors, and so is able to break them out of the ground. At least 90 per cent. of anchors now made are stockless.

Sea Anchor.—This is an arrangement well known to those who go to sea, and particularly those who have been wrecked, or who have had to take to the sea in an open boat. It is intended to break the force of the waves, in bad weather, so that a boat can ride out a storm in comparative safety. It consists of any spars that are available, any sails, and any weights &c., that can be obtained. The spars are lashed together, the sails with them, and the weights slung from them. The boat is made fast to a span connected to the two ends of the arrangement, and rides behind it, just as she would behind an anchor. The best position for a boat, in a seaway, is head on to the sea, the waves breaking at her bows and going right over her. They do less damage in that way than if they are allowed to take the boat broadside on. The sea anchor helps the boat to keep the position, head on to the waves, and it breaks the force of the waves as they come up.

Anchorages. — This term denotes the methods of attachment of ropes and chains to their drums, or to rigid fixtures; the fast ends of brake straps, the attachment of the chains of suspension bridges into their piers, and similar instances.

Anchor Crane.—A light crane used for lifting ships' anchors. It is of triangular-framed type, comprising post, jib, and single or double tie rods. All dimensions for these members are given by "Lloyd's" for anchors of different sizes, ranging from 20 to 60 cwt.

Anchors, Tests of. — Anchors formerly made of wrought iron are nearly supplanted by those of cast steel. Lloyd's tests, applied to these, are as follows:—If the anchor is in more than one piece, each piece is subjected to the same test. The anchor, or piece, is raised to a given height, and dropped on an iron slab. By "given height" is meant that the *lowest* part of the anchor when suspended shall be at the height named. For anchors of 15 cwt. and below, the height is 15 feet. If above 15 cwt. the height is 12 feet. Anchors of Admiralty pattern are dropped successively from two positions, one with shanks and arms horizontally, the second with the crown downwards, two iron blocks being placed under it, these being of sufficient height to prevent the crown of the anchor from touching the slab.

If these tests are passed, the anchor, or piece, is slung up, and hammered with a sledge weighing not less than 7 lb., and it must give a clear ring such as to satisfy the inspector that all the parts are sound.

A cold bending test is made on a piece 8 inches long, cast on, and cut from each casting, and turned to 1 inch diameter. It is then bent cold by hammering through an angle of 90 deg. over a radius of $1\frac{1}{2}$ inches, without showing indications of flaw or fracture. If this fails, the anchor is condemned. In some cases the piece is cast large enough to permit of cutting four test pieces.

Anchors are annealed, during a period of from three days for small sizes, to six days for those of large size. They are then stamped "Annealed Steel." But Lloyd's inspectors examine the castings also before they are annealed, in order to detect any cracks or other defects which might not be so obvious subsequently to annealing.

Angle (from Latin *angulus*, a corner).—In geometry an angle is the inclination of two straight lines to one another, which meet together, but are not in the same straight line. Angles are measured by the number of degrees they contain, the *right angle*, containing 90°, being the standard by reference to which other angles are compared. An *acute angle* contains less than 90°, and an *obtuse angle* more than 90°.

In the first book, Euclid gives some valuable axioms relating to angles, summarised below.

1. The angles which one straight line makes with another on the same side of it are together equal to two right angles.

2. The greater side of every triangle has the greater angle opposite to it.

3. If a straight line falls on two parallel straight lines, it makes the alternate angles equal to one another.

4. The three interior angles of any triangle are together equal to two right angles.

5. If one side of a triangle be produced, the exterior angle is equal to the sum of the two interior and opposite angles.

in marking out work, and the methods of making angles of different degrees both with compasses and set squares are given, Figs. 64 and 65.

To construct an angle of 90° with compasses.

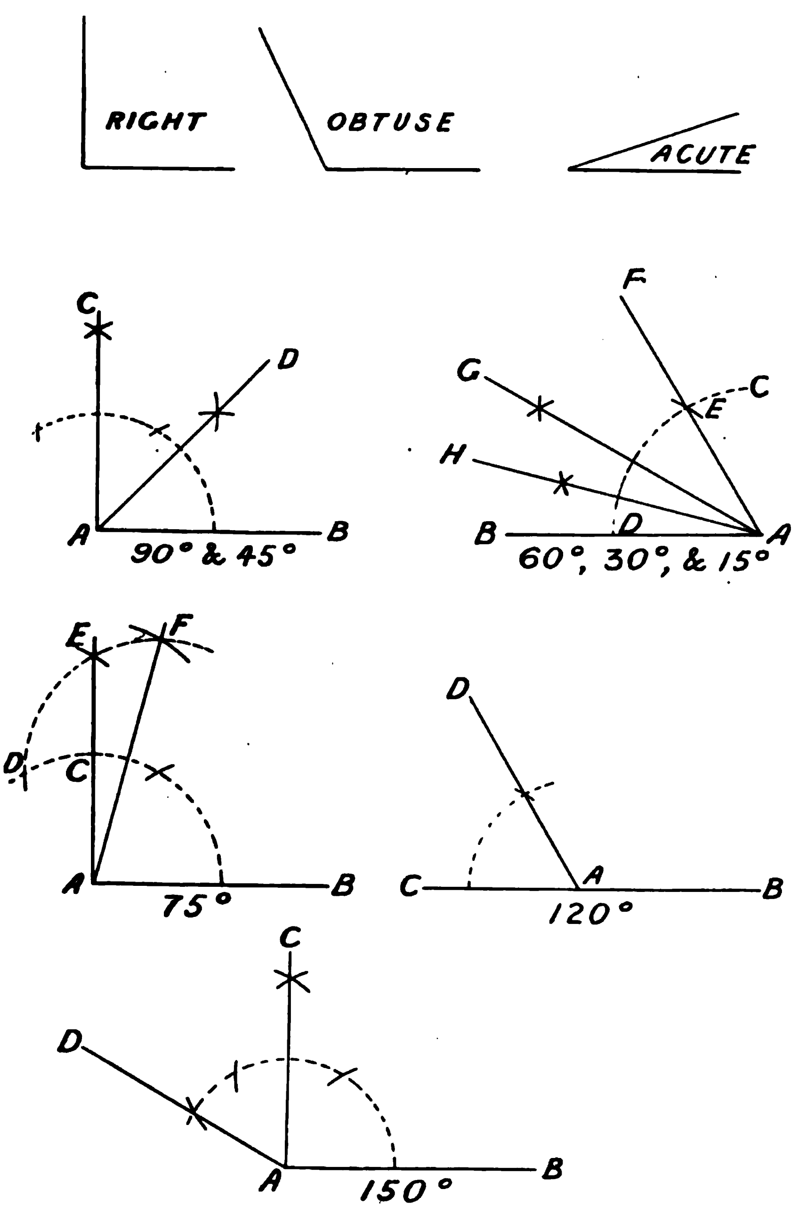

Fig. 64.—The Construction of Angles with Compasses.

6. The angles at the base of an isosceles triangle are equal.

The construction of angles repeatedly occurs

At A erect a perpendicular AC to AB. BAC is therefore an angle of 90°.

An angle of 45°. Construct an angle of 90°

as above, and bisect the angle BAC by the line AD. BAD is an angle of 45°.

An angle of 60°. With centre A and any convenient radius describe the arc CD. From D with the same radius cut CD in E. Through E draw AF. BAF is an angle of 60°.

An angle of 30°. Construct an angle of 60° and bisect it. Then the angle BAG is an angle of 30°.

An angle of 15°. Construct an angle of 30° and bisect it. BAH is an angle of 15°.

An angle of 75°. Erect a perpendicular AE. With centre C and the same radius as that used in erecting the perpendicular describe an arc cutting DE in F. Join AF. Then the angle BAF is an angle of 75°.

shape and has two angles of 45° and one of 90°. The set square of 60° contains angles of 90°, 60°, and 30°. The following diagrams, Fig. 65, show clearly how these two set squares, alone, and in combination, may be arranged to make almost any angle.

Angle Bending Machine.—There are several special types of machines made for this purpose, distinct in character from bending machines used for plates and sheets. The latter may be used for some classes of angle bending, by inserting narrow rolls at one end of the rollers, grooved to take angles and tees. But these are only makeshifts, and not suitable for all bends.

Angle bending machines deal also with tees,

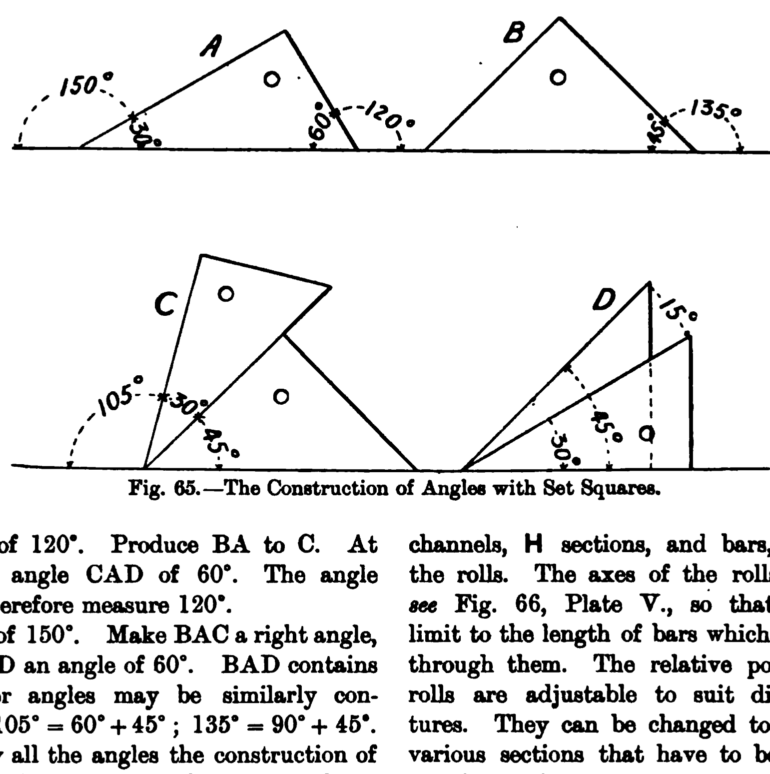

Fig. 65.—The Construction of Angles with Set Squares.

An angle of 120°. Produce BA to C. At A make an angle CAD of 60°. The angle BAD will therefore measure 120°.

An angle of 150°. Make BAC a right angle, 90°, and CAD an angle of 60°. BAD contains 150°. Other angles may be similarly constructed :—105° = 60° + 45° ; 135° = 90° + 45°.

Practically all the angles the construction of which is described above can be made with set squares in much less time, and, with due care, with equal exactness. The point to remember is that the angles made by one straight line which stands on another are always equal to two right angles or 180°. The two set squares in common use are those of 45° and 60°. The former is the half of a square in

channels, H sections, and bars, by changing the rolls. The axes of the rolls are vertical, *see* Fig. 66, Plate V., so that there is no limit to the length of bars which can be passed through them. The relative positions of the rolls are adjustable to suit different curvatures. They can be changed to accommodate various sections that have to be bent. They are driven by spur gears situated below the table, over the surface of which the bars slide. The rollers in the best machines can be raised and lowered to admit webs of different thicknesses between their bottom edges and the table. In some cases the roll is in two parts, the upper adjustable on the lower to admit various thicknesses of web. The lower

part goes mostly below the table, the face of the groove standing up about $\frac{1}{8}$ inch only, to raise the angle being bent just clear of the table, to prevent useless friction. A wide roller is fitted to each side of the table to support the entering and leaving ends of the iron being bent. These machines are generally belt-driven, but recent ones have been fitted with a motor drive.

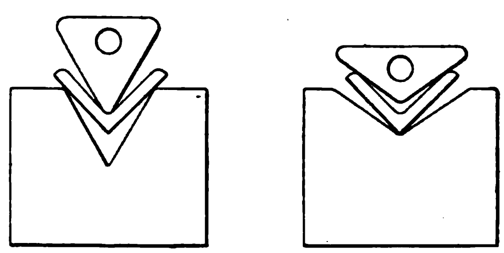

Fig. 68.—Dies for Setting Acute and Obtuse Angles.

Machines of this kind are designed for bending to curves only. If angular shapes, or these in combination with curves, are wanted, another kind is used, the bulldozer, and others built on that model, and the work is squeezed into shapes between die blocks of cast iron inserted in the machine. These are operated in horizontal lines by a moving ram, actuated by a crank, or by hydraulic power. The machines are essential when large numbers of similar pieces have to be bent, as in bridge and girder work, *see* Fig. 67, Plate V.

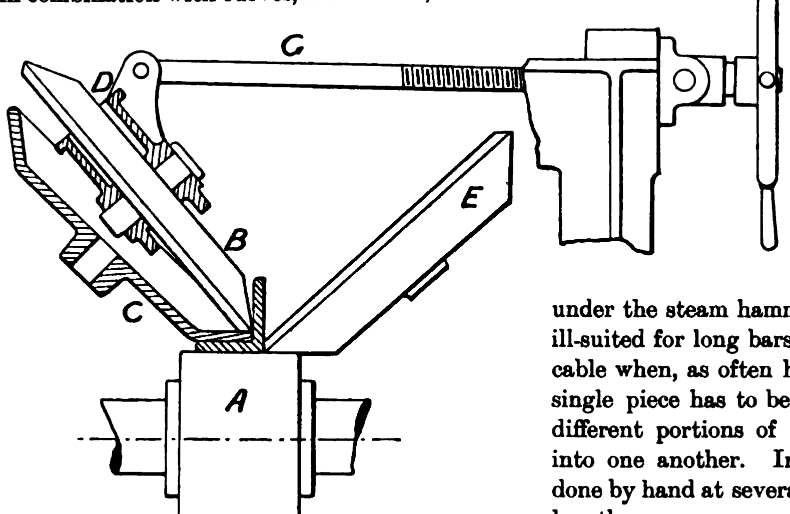

Fig. 70.—Open Bevelling.

Machines built on this general model are frequently used for straightening as well as bending, in which case no dies are required. The angle, or channel, is laid against two abutment pieces, and the moving ram is brought against it at a point midway between the abutments. The degree of pressure brought to bear determines whether the bar shall be either bent or straightened. These are also frequently termed beam bending machines, or beam straightening machines, because they are used for channels, and **H** sections.

In another form, made in shops for special use, a die block is used in combination with a moving roller, the latter squeezing the angle or tee, &c., down on the edge of the block, shaped as required. The various blocks required for different bendings are set between cheeks, and the movements of the roller —power-driven—have sufficient range, in slots, to permit of its lying close round the work.

Angle Bevelling Machine.—Alterations in the bevel of right-angled sections can be easily done in short lengths in dies, under the steam hammer, Fig. 68, but these are ill-suited for long bars, while they are impracticable when, as often happens in shipbuilding, a single piece has to be set to different angles at different portions of the length, and merging into one another. In such cases the work is done by hand at several heats, and in successive lengths.

A machine, Fig. 69, Plate VI., is used in many yards to do this work by means of rollers operating on one web, while the other is confined between other rollers between which it is passed. The machine is equally capable of bevelling a bar to one continuous angle, or to several angles during a pass.

This is effected by carrying one web or flange of the angle along the edge of a rotating drum A, Figs. 70 and 71, on which it is pressed by a bevelled roller C in Fig. 70, E in Fig. 71.

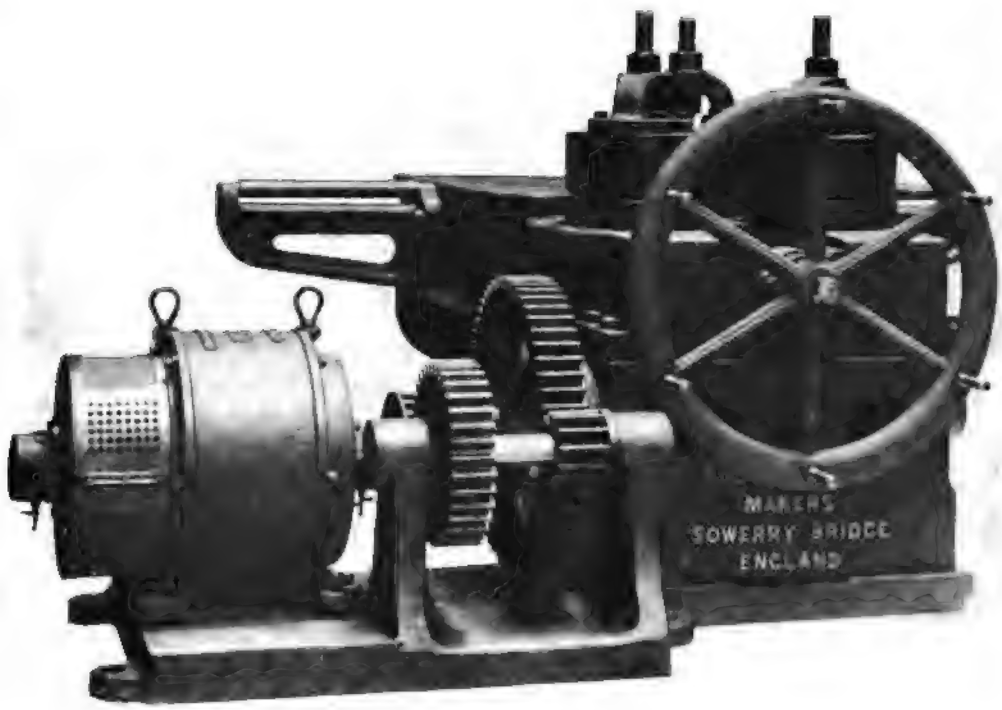

Fig. 66.—Motor-driven Angle Bending Machine. (Rushworth & Co., Sowerby Bridge.

Fig. 67.—Hydraulic Press (14 in. diameter by 16 in. stroke) for Bending and Setting Angles and other Sections. (Sir Wm. Arrol & Co., Ltd., Glasgow.)

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Another roller B above, the axis of which is capable of adjustment in its bearings in the bracket D, to suit any bevel, turns the free web or flange to the angle corresponding with the angle to which its axis is set, and either acute, or obtuse, depending on the arrangements and angles of the rollers. The changing of

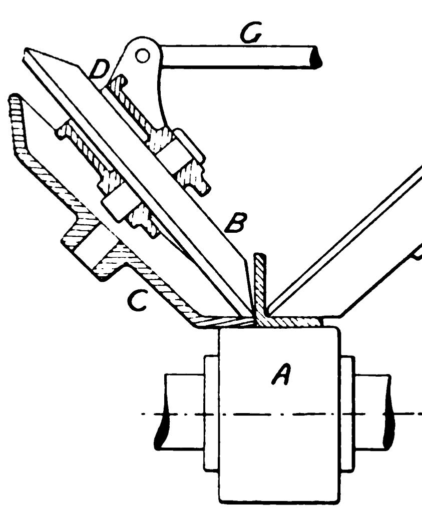

Fig. 71.—Shut Bevelling.

the axis to produce variations in angles can be done while the machine is running by the attendant turning a hand wheel F operating the screwed rod G, and the particular angle desired is indicated by a pointer moving over a graduated dial. The time at which a change has to be made is known by marking the bars at the positions where changes have to be effected before the bars are inserted in the machine.

Angle Board.—A board used chiefly by patternmakers for planing triangular strips of wood, and for hollowing out one face of such strips in making fillets for patterns. The board is usually from 2 ft. to 3 ft. long, by about 8 inches wide, by 2 inches thick, Fig. 72. A series of Vee'd grooves of different sizes run the length of its upper face, and a stop is required near the front end, the same as on a shooting board. A strip of wood with square angles will lie in one of these grooves in a tilted position which would not be possible on a flat bench, and an angle can thus be planed along the strip without difficulty.

Angle Bracket.—Any form of outstanding bracket used for the support of portions of mechanism, so-called because its acting faces make a right, or other angle. It is always necessary, for stability, to introduce a stiffening rib or ribs to prevent deflection or fracture. In the case of cast brackets the ribs are cast with the faces; in constructional work, angles and other sections are used to form the stiffeners. It is especially necessary to have angle ribs to support flanges which have to withstand the strain of bolting, as in foundation plates and bed plates, &c. The use of angle brackets necessarily complicates manufacture; in pattern work the ribs or brackets have often to be left loose, for withdrawing in the mould, and extra work is involved in the plater's processes, in bending special shapes of stiffeners.

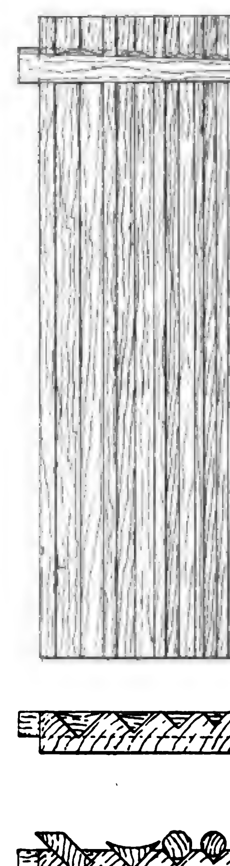

Fig. 72.—Angle Board.

Angle Chuck.—*See* **Angle Plate.**

Angle Cropper, or Angle Iron Shears.—A shearing machine with a Vee-shaped knife and bolster, between which angle bars are passed and shorn off to definite lengths. An addition of this kind is often made to ordinary shearing machines, but when angles are constantly being cut, as in bridge work, the special machine is necessary. The angle cropper, like other shearing machines, is driven through double spur gearing, with a heavy fly-wheel. Many machines are motor-driven, a raw hide pinion on the motor shaft driving the first spur wheel. A stop motion is fitted to an eccentrically driven slide as in shearing machines.

Angle Edge Planing Machine.—A special

form of machine designed for shipyard work, for planing the edges of angles and tees for making water-tight joints, and thus save the expense of caulking, while producing a better job. The angle, &c., is carried on rollers through the machine, while two broad cutting tools in separate holders plane the edges at one traverse. The tool holders are adjustable, and the angles need not be straight, since they are supported by the rollers, in direct opposition to the cutting tool.

Angle Iron, Angles, Angle Sections.—Denotes rolled sections, the two webs of which form right, or other angles—acute, or obtuse. The term "angle iron" sticks, because it is a

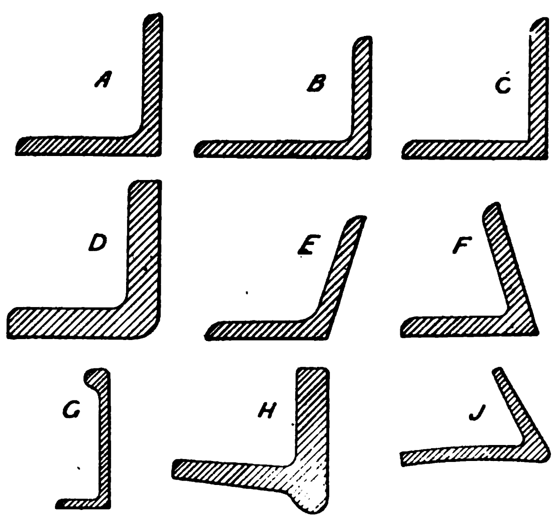

Fig. 73.—Typical Angle Sections.

survival from a period when all such sections were rolled in wrought iron. At the present time angles rolled in this material bear a very small proportion to those made in steel. The terms angles, or angle sections, therefore express more precisely the meaning, and the term "steel" or "iron" should be prefixed, as steel angles, iron angles.

Angles are "equal," Fig. 73, A, when the widths of each side (or leg, as it is often called) are alike; "unequal" when one is wider than the other, B. The number of standard rolled sections is very large, so that there is no good reason for specifying unusual sections, such as those varying by $\frac{1}{8}$ths or $\frac{3}{16}$ths, for which extra prices are charged. The usual sizes of equal angles range from 1 to 8 inches, and of unequal sizes from $1\frac{1}{2}$ by 2 inches, to 4 by 7 inches. Each standard width is rolled in various thicknesses, as say from $\frac{3}{16}$ to $\frac{3}{8}$ inch; or $\frac{3}{8}$ to $\frac{7}{8}$ inch; or $\frac{1}{2}$ to 1 inch. In standard angles there is a radius in the root, and the outside angle is keen. In "square root" angles, C, the inner radius is obliterated. Sometimes the edges also are square. In "round-backed" angles, D, a convex radius is substituted for the outside angle. Obtuse angles, E, and acute angles, F, are used when the plates or bars to be united are not required to stand square, but at various bevels. These are not rolled, except to order, in the same range of sizes as the square angles, since they are not required so frequently. Their chief utility lies less in engineers' constructional work than in shipbuilding. When small quantities are wanted in the shops, the square angles are taken, and set to the bevel required between top and bottom dies, Fig. 68, under the power hammer. If larger quantities are wanted, many firms use an angle bevelling machine, Figs. 69-71, which can be set to roll angles of different bevels as required.

Bulb angles, Fig. 73, G, are a stiffened form used chiefly by shipbuilders. They differ from the common form in the thickening of the edge of the deeper section. This has the same effect as a stiffening flange, in rendering the vertical web more rigid. Occasional forms of angles are shown at H and J, but these and some others are seldom rolled except to order.

With the exception of the bulb angles, these sections are generally used as a means of union for plates and bars. The alternative would generally be flanging, or the employment of rolled sections of less simple forms. Angle sections enter thus into a vast quantity of plated work for beams, bridges, and other structural designs, riveting being the means of union employed.

The weights of angles are given by the manufacturers per foot run, for all the various sections, which renders calculations of the weights of structures easy.

Angle Iron Forge.—This differs from the smith's forge in having a wide area of sheet iron between the hearth and the wall. This is

necessary in order to permit of the handling of large rings, or bars having long curves, which could not be laid in an ordinary smith's fire without hanging out over the sides. It has also a bent bar supported on loose legs at one side to support long projecting ends of work.

Angle Iron Furnace.—The ordinary reverberatory furnace of the plater and boilermaker is utilised for the heating and annealing of angles, tees, and other sections.

Angle Iron Rings and Sweeps.—These are either external or internal, according as the flanges are situated outwardly or inwardly. They are bent from angle sections, or they are, if small, often stamped from a piece of plate, in dies under a hydraulic press, or steam hammer. The advantage of the latter method is that a good radius is obtained, which in steam boiler construction is most desirable. Cases of this kind occur in the union of plates to firebox crowns and to shell crowns, as alternative to the flanging of the uptakes. This practice has developed solely in consequence of the high ductility and capacity for elongation which mild steel possesses. It is not possible to do such work in common wrought iron, for this would crack in the act of punching. Rings and sweeps in angle and tee iron can be bent without any welding, like that which is necessary at corners when bending is done to sharp angles.

Large rings are always made by bending and welding. They are then turned round against bending blocks (*see* **Angle Iron Work, Bending Blocks**) and welded by scarf joints if of light section, or by the glut, or Vee welds, if heavy. In the first case a lap of about an inch is allowed for "shutting up."

The extreme ends of an angle section which have to be welded are bent to their curvature, Fig. 74, before the main bending is done round the block, because it is easier to do that work before than after the main bending. And when the ring has been turned round, a clip or clamp is fastened to it before the weld is made, otherwise it would not come out to the right dimensions after welding.

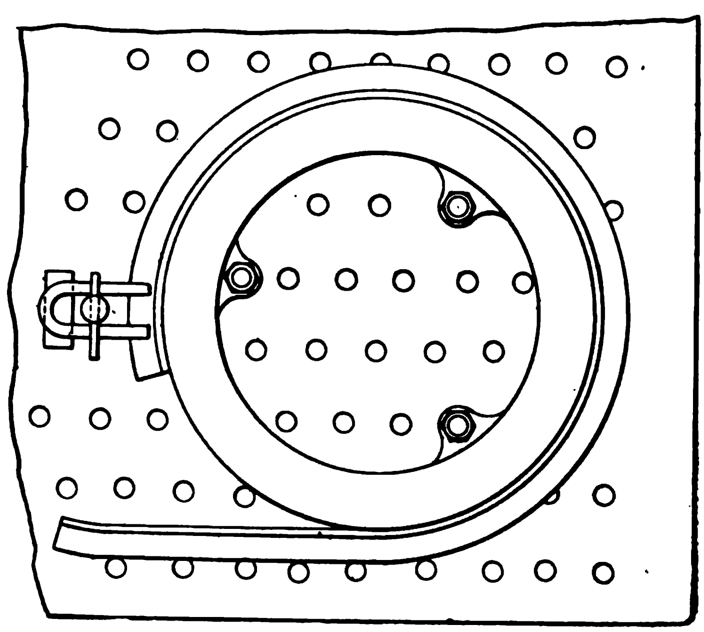

Fig. 74.—Bending Large Ring on Circular Block Bolted to the Levelling Block.

In most cases also a ring of small dimensions has to be corrected after welding, by the aid of an appliance like Fig. 75. The conical stand does not correct a truly parallel ring, while the block in Fig. 75 does. Loose segmental blocks fit the interior of the ring and are driven outwards by the circular-tapered pin in the centre. At the same time the flanges are set down on

the levelling block with the flatter. This requires a special heating of the ring, and to permit of the setting and correction, rings to be so treated are welded up a trifle small in diameter, say $\frac{1}{32}$ to $\frac{1}{16}$ inch. The larger rings must of course be corrected by hand.

For bending rings and curves of large radii, and considerable length, the assistance of the levelling block is generally necessary. A templet block is fastened upon this, and becomes a guide for producing the curvature. The steadiness of the latter is assured by the massive block to which it is attached. Figs. 74, 76, 77, 78 show such blocks for angle rings.

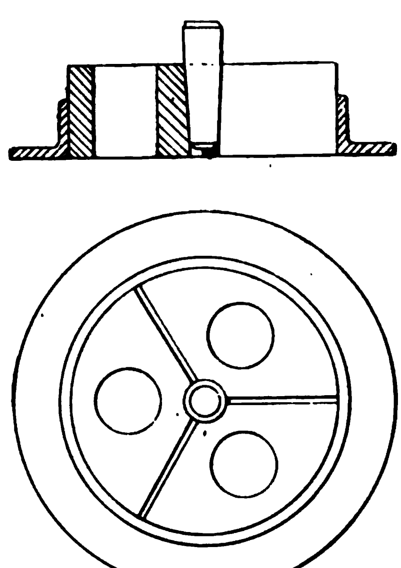

Fig. 75.—Method of Correcting a Ring.

Small rings like those in Fig. 75 are a standard form for uniting the uptakes of vertical boilers to the boiler crown. They are rather an awkward job, because the flat flange is subject to considerable tension during bending, but the bending is nevertheless done without cutting and welding as is the practice when bending takes place at sharp angles.

For bending these, a templet block is used. It is simply a disc with a round hole in the centre by which it is held down to the levelling block with a bolt like that in Fig. 81. The angle iron being heated, one end is clamped down with a holdfast, numbers of which are employed in work of this character. But there are several rough and ready ways of holding work down to the levelling block. A common one is shown in Fig. 74. It is a loop of iron simply, one end resting upon the flat flange of the angle iron, the other end packed up on a thickness piece, and the cottar of a bolt passing across and being driven tight, holds the loop down fast upon the angle iron.

The angle iron being held in some such fashion is pulled round the block, the flatter being constantly in requisition to correct puckering. It is finally welded. The entire bending of small rings is done at one heat.

With regard to the minimum dimensions of rings that can be bent, this depends on the width of the horizontal flanges. Steel will stand twice or thrice as much bending as iron. About 8 inches inside diameter is the limit to rings of $3 \times 3 \times \frac{1}{2}$ inch of steel. This limitation is due to the great difference in the length measured round the inner and outer diameter, about 18 inches, showing the enormous amount of stretching that has to be done on the outside length.

In turning large rings and sweeps, a heat is first taken over a portion of the angle, either in the forge fire, or preferably in a reverberatory furnace. In the latter, a longer portion can be heated, and its temperature is more uniform than that obtained in the forge. One end of the iron is then made fast to the block by any convenient attachment, as by a clip driven over work and block by the hammer simply, or held by cottar bolts, the clips embracing the angle iron securely. The opposite arm of the clip takes its bearing against the back of the block. When one end is thus secured, a striker takes hold of the free end and pulls it gently round the templet block. While he is doing this, the smith holds the flatter in his hands, and moving it from place to place, wherever the angle iron manifests a tendency to pucker up, another striker deals the necessary blows upon it. Occasionally the flatter is used to correct the vertical sides of the angle, to cause it to lay closely to the bending block. If the angle is a long one, it is necessary to drive clips at intervals to prevent local bulging from taking place. As the iron cools down, the flatter blows are con-

tinued until all puckering is reduced, and until the angle lays closely to the block on the top and the side all the way round. If the angle is a long one, two or three heats may have to be taken.

when first taken. The reason is that the metal on the larger diameter becomes stretched considerably more in the act of bending than that on the smaller, and the width of the web there-

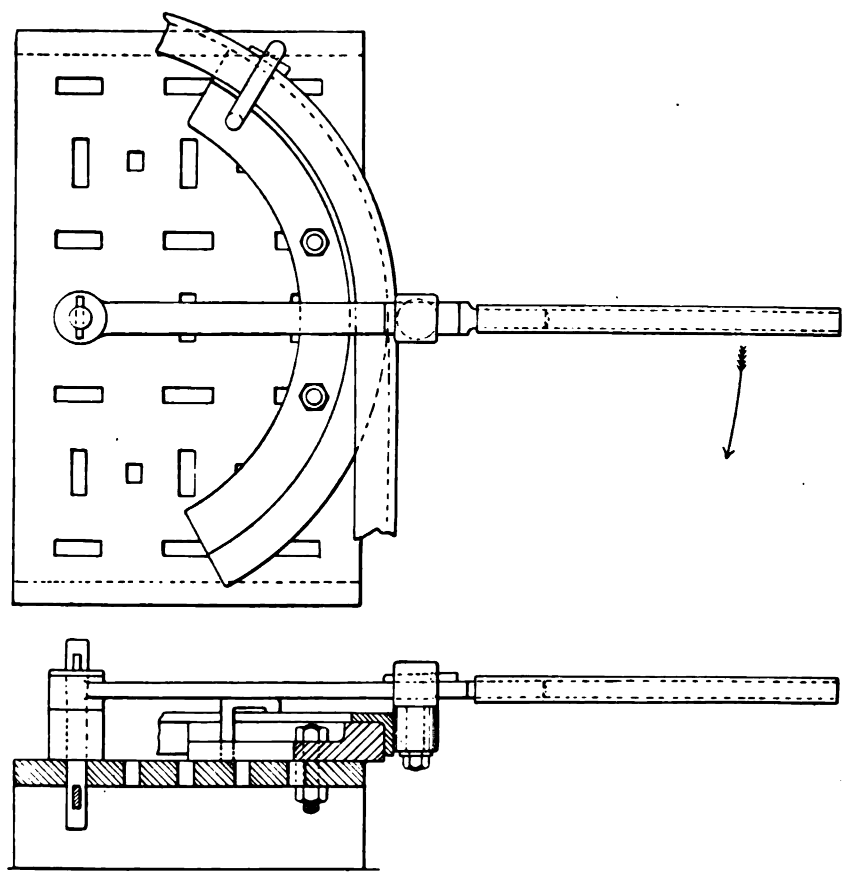

Fig. 76.—Bending Internal Angle around a Block.

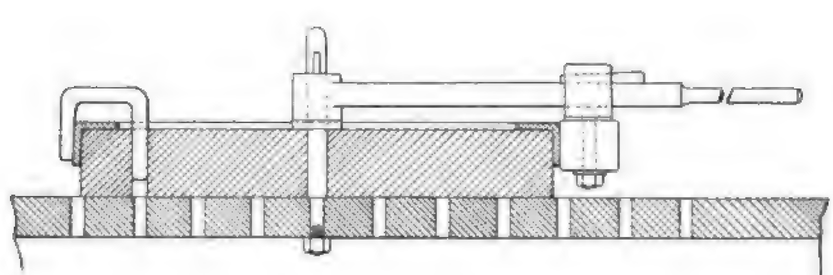

Fig. 77.—Bending Ring round a Block.

To bend rings of bevelled sections is rather more troublesome than those of right angles. The bevelled web does not come out so wide in the finished ring as the angle section measures

fore becomes lessened by $\frac{1}{4}$ inch or more on a width of about 3 inches. If, therefore, the original width is required, an angle of larger size must be taken.

Bevelled rings must have their angle sections set to the bevel required before the bending is

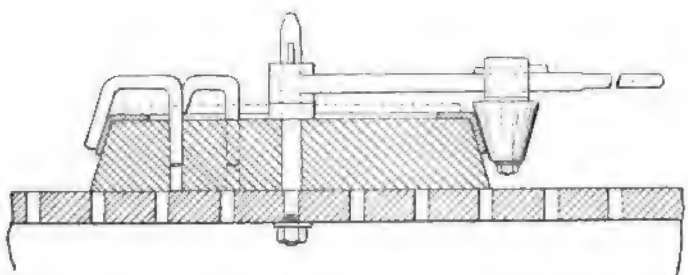

Fig. 78.—Bending Internal Angle Bevelled Ring round a Block.

commenced. Afterwards the work of bending proceeds as in right-angled sections.

A neat method of removing the puckering from a bevelled ring is to do so on its own block. This is done by taking another heat over the entire finished ring, laying it on the block, covering it with a disc indicated by the dotted lines in Fig. 78, cottaring the latter down firmly upon it, and then making the necessary corrections with the flatter.

The levers shown rigged up for bending in Figs. 76, 77, and 78, are provided with rollers, which are pressed against the work. It will be noticed that the positions of these are not fixed at one radius, but that they can be rapidly cottared in different positions along their bars. The reason is twofold—first, to permit of using the same lever and roller for rings and sweeps of different radii; second, to allow of readjustments of the roller inwards as the work proceeds. Some bending levers have no rollers, but a rigid pin is turned downwards to coerce the angle. This permits of no readjustments, and it causes much friction, so that it is only a cheap and makeshift method.

The heat for bending angles is a full red, verging on a white heat for iron; for steel the heat should not go beyond a full red. Rapidity of manipulation and workmanship is requisite, so that the work shall be done before the blue or black heat is reached, work done at that heat being injurious. A good deal is done in the shops, however, but nevertheless the practice is to be strongly condemned, and it is better to put the iron or steel back into the fire again and reheat, rather than continue hammering while the metal is black hot. There is no risk at all in making slight corrections for curvature and setting over of flanges after the material has become quite cold, and this is commonly done. But if a piece of work is not actually finished before it gets below a faint red heat, it ought to be reheated.

When angles are heated at the forge for welding, the portions to be welded are enclosed in brickwork away from contact with the fuel. Loose firebricks are used, arranged to suit the size of the portions to be heated, and this portion is located as nearly over the blast pipe as possible.

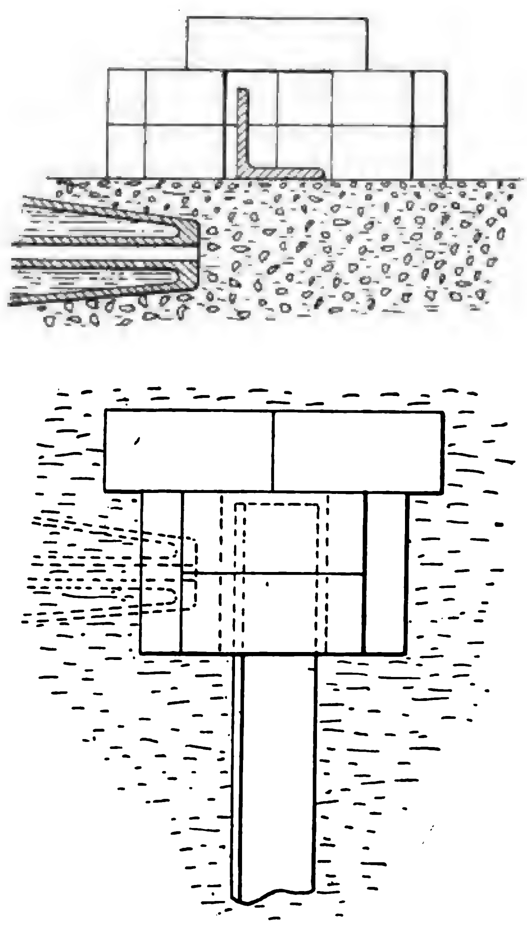

Fig. 79.—Method of Bricking Round Angles and other Sections at the Forge.

Fig. 79 shows a typical arrangement for heating one end of an angle. When a middle portion has to be heated, the angle goes through an archway formed of bricks, enclosing that portion alone, leaving the ends uncovered. Fuel is heaped over the angles in the vicinity of the brickwork to confine the heat, though this is not indicated in the figure. Tees are heated similarly. But when small and medium dimensions are exceeded, the reverberatory furnace must be used for heating.

The estimation of the lengths of angle to be cut off for welding up into a ring of given size is not quite so simple as that of getting the length of a bar of plain rectangular, or circular section, in which the mean of the cross section is taken. There are four rules at least known to the writer for getting the lengths of angles, but they give results within a trifle of each other. One only need be given here.

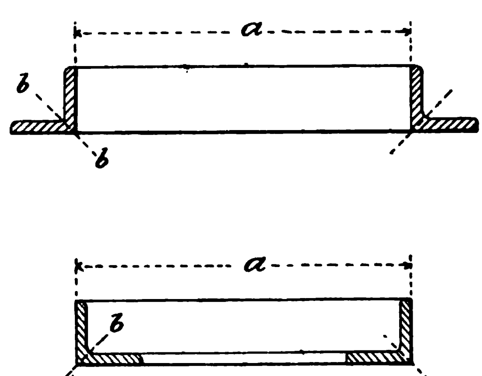

Fig. 80.—Illustrates the Method of Calculating Lengths for External and Internal Rings.

For external rings, Fig. 80. To the internal diameter *a* add twice the diagonal thickness, taken through the throat *b-b*, and multiply the sum by 3·14159.

For internal angles. From the external diameter *a* subtract twice the diagonal thickness, *b-b*, and multiply the sum by 3·14159.

It will be noted that no account is taken of the horizontal flanges in these rules, but only of the vertical flange and the thickness of metal in the throat. In an external ring the horizontal flange being outermost, is extended in the act of bending, but with an internal ring the flange is compressed and puckered. These actions impose minimum limitations on the size of rings for a given section of angle. But rings that could not be bent in iron can be done in steel. Because also of this uncertain behaviour of the horizontal flanges, which varies with the character and extent of the heats taken, and with the quality of the iron or steel used, variations occur in the calculated and the exact diameters of different rings.

Angle Iron Rolls.—*See* **Angle Rolls.**

Angle Iron Shears.—*See* **Angle Cropper.**

Angle Iron Smith.—This is not a very comprehensive definition of a craftsman whose work extends much beyond the operations done on angles. It really distinguishes the trade apart from that of a plater, or a boilermaker, or riveter, all of which trades are carried on in the same shed or shop.

The work of the angle iron smith lies at the forge chiefly, comprising all the operations involved in the working up of all rolled sections that are used in bridge and boiler construction. It includes cutting off, bending, setting, welding, and flanging of all kinds, whether done by hand wholly or assisted by machines. The wages are high, as the work is of a responsible character, since materials are liable to be spoiled by overheating, by cracking, or crumpling, and by imperfect welding. *See* **Angle Iron Rings, Angle Iron Work.**

Angle Iron Tests.—*See* **Forge Tests.**

Angle Iron Work.—This is an important department of the bridge and girder shops, of plating, and boiler work. The operations are not restricted to angles, but include those on all other rolled sections, on bars and rods, tubes, and flues. One of the principal details is the making of welds, others are straightening, bending, flanging, and all the operations allied thereto, much of which will be treated under other headings.

To a person unacquainted with the trade, it might seem that the work involved would not demand a high degree of skill, because the sections used are all delivered ready rolled and finished into the shop. In this respect it differs as a trade from some others, in which processes are entirely formative, or largely so. But such a view is not correct, or angle iron smiths would not be paid rather higher rates than their

co-workers in boiler and plating shops. The reason is that the ready-rolled sections have to

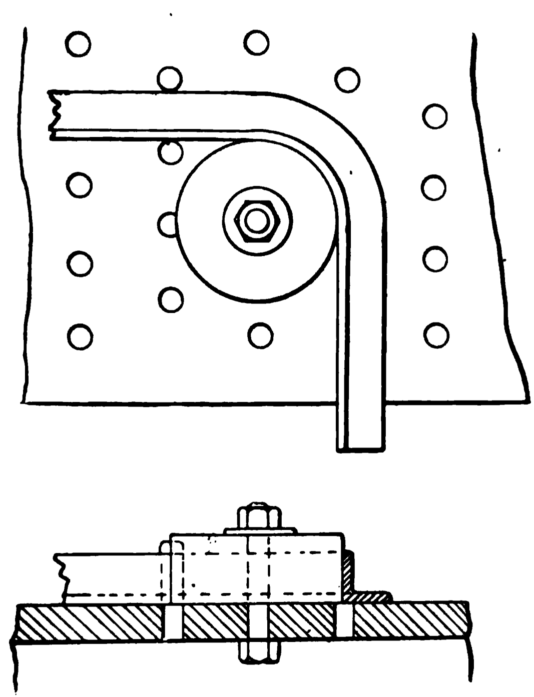

Fig. 81.—Bending Angle to Small Radius by the insertion of Pins in a Block.

be subjected to various processes requiring a high degree of skill and experience, the principal among which are bending, and welding, the estimation of lengths, and allowances, and careful corrections to remedy the distortions inseparable from the carrying on of these operations. It is one of the trades in which apprenticeship is still retained, or its equivalent of several years of training, and the number of good craftsmen is generally unequal to the demand for them.

Various appliances are used to facilitate the work of bending sectional forms. As a rule these are necessary, although for odd and occasional jobs they may be dispensed with, work being bent by hammers alone and tested with templets. Bending may be done in a vertical, or in a horizontal plane. The former is suitable for sections of no great length, but the latter is necessary when long pieces have to be handled.

The basis of bending operations may be the anvil, or else the combined levelling and bending block (*see* **Bending Blocks**), the former for comparatively small work, the latter for small and massive alike. The work is sometimes done directly on these appliances, but generally on a block attached to one or other of them. Another way in which blocks are secured is to a stand having a rectangular form in plan, resting on the shop floor.

A good deal of bending is done on the bending and levelling block, without any further aids than those afforded by pins dropped in the holes, as helps to bending by. This method depends on the character of the shop, and on the nature of the work. Odd jobs do not pay for the casting of special bending blocks, but in shops where these accumulate in the course of years, something may generally be found nearly or quite accurate enough for bending odd jobs by. Without such aid, pins are inserted in any holes which happen to be conveniently situated, Fig. 81, to retain the portion of the angle that has not to be bent, while the portion adjacent, having been first heated in the forge, is pulled round by hand against other pins. One, two, or more distinct curvatures can be imparted in this way, in the same, or in opposite directions.

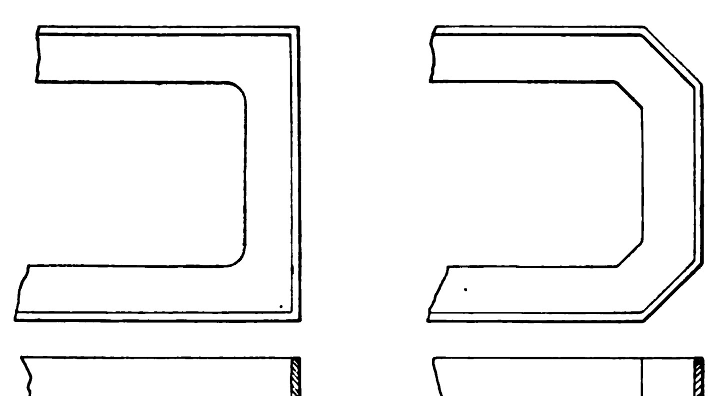

Fig. 82.—Common Forms of Frames made by Bending and Welding.

Such bending is not so accurate as that

which is done on regular bending blocks, but subsequent corrections are necessary. These are effected by the sledge, or by hand hammers, while the section lies on the block, and they involve corrections both of horizontal and vertical flanges. A templet of wood or sheet metal is also generally desirable for checking results by, though often there is no other test but a line chalked upon the same, or upon another block close by, or on a board, or a floor where the work is marked out to full size.

The bending of angles L, of joists I, and channel sections C is done either on internal or external faces. The sectional forms of the working edges of the bending blocks made are therefore exactly the reverse of the sections to be bent, with, in certain cases, a little allowance for shrinkage. Examples will be found under **Bending Blocks**. In the other or longitudinal direction the form is just the counterpart of the curvature, or the angles, Fig. 82, required, also with allowance for shrinkage. In the case of complete rings to be welded after bending, allowance has to be made for the weld joint. Lengths also differ, according as the bending takes place with flanges internally or externally. *See* **Angle Iron Rings**.

The usual methods of bending are as follows: The piece being heated over the length which has to be bent, is cottared down, Fig. 83, at one end first, and the other end is pulled round the block, by the smith or his helpers, sometimes by hand, using nail bags to hold by frequently, and, especially in the shorter lengths, by a lever forked to slip over the end of the angle. During the act of pulling round, the flanges become puckered, and the angle does not lie uniformly close to the block. The smith corrects the puckering with hammers, or with the wooden mallet, and he, or a helper, drives in pins close to the edges, to maintain a close contact of the angle with the block. In this way the bending is followed closely in detail, and kept under coercion. There is a difference in the method of cottaring and holding, according to whether the angles are internal or external (compare with Figs. 74, 77, &c.), the object in each case being to hold the section down flat, and to keep it close against the vertical edge of the bending block.

In heavy sections the pulling round of the free end of the piece is too hard a task to accomplish without mechanical aids. In such cases the assistance of a long lever and a friction pin or roller (compare with Figs. 76-78) is necessary. Examples of this kind occur in bending rails, channels, and square bars for the foundation rings of vertical boilers. The rig-up used in these may be self-contained and independent, or be bolted to the shop

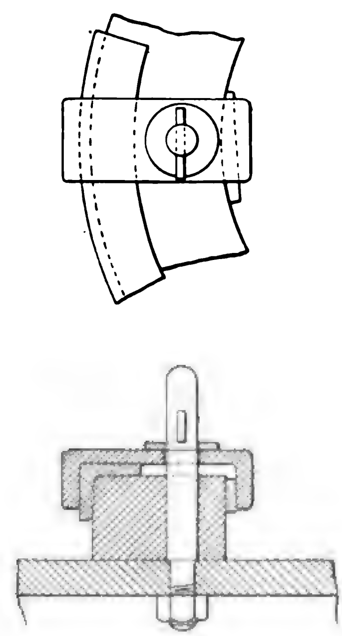

Fig. 83.—Method of Gripping Angle.

bending blocks. The movement of the lever is accomplished by men pulling at the free end, and the lever has to be moved backwards and forwards repeatedly over short sections of the work. There is no perceptible clearance, but the distance between the edge of the roller and the edge of the block is practically the same as the thickness of the section being bent. When large numbers of pieces have to be bent alike, machines are employed actuated by spur and worm gears. Many of these are made in the shops to special requirements, but they are also built by the machine tool makers. *See* **Angle Bending Machine**. Illustrations of blocks on which hammering is chiefly done are given in Fig. 84.

Welding, as done by the angle iron smith, differs in many respects from that performed by the ordinary engine smith. The only features which they have in common are the heat for welding, the fluxing, and the actual closing of the weld. The scarfed joint, so much employed by the engine smith, is employed less by the angle iron smith, and the methods of heating and of holding the work are generally different. The forge of the angle smith is open on both sides, and rather larger than the common smith's forge, and fire-bricks are used to enclose the ends which are being raised to the welding heat. The bricks are built up over and around the nose of the tuyere, and all but the opening for the work is covered and enclosed by small coal or coke (*see* Fig. 79, p. 122). No fuel comes in contact with the metal, a precaution of special importance, because the surfaces to be welded are generally of large dimensions, and no dirt must be permitted. Another important matter is the method of holding work for welding, coercion being essential in the case of rings, and frames of large dimensions. These have to be gripped properly, before the welding heat is taken, without which precaution the ring or frame would suffer distortion in the act of handling, and removal from the fire to the anvil or block. These rigs are made in various ways, as happens to be most convenient for coercion and manipulation (*see* Fig. 85). Some fulfil one function only, others combine both.

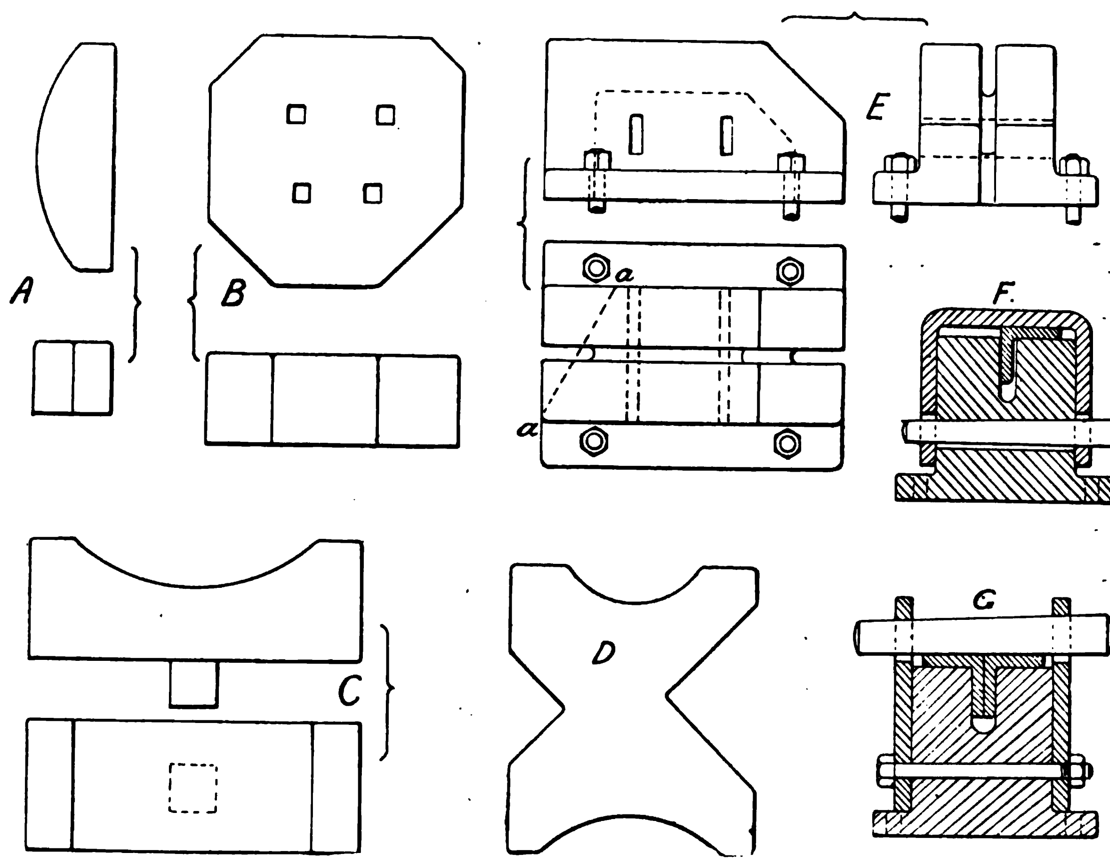

Fig. 84.—Typical Blocks for Angle Iron Work.

A. Block for bending angles to curves. B. Block for bending to angles. C. Anvil block for bending in a vertical plane. D. Block combining angles, and curves. E. Block for setting angles or tees upon in considerable numbers. (With the block bevelled as at a-a, acute or obtuse angles can be bent.) F, G. Methods of cottaring.

With regard to the shapes of welds, one of

the principal is the glut, which is seldom employed by the engine smith. The butt and the scarfed welds are also employed, the latter for angles and tees are characterised is that portions of the metal have to be severed as a preparation for welding. This is due to the great amount

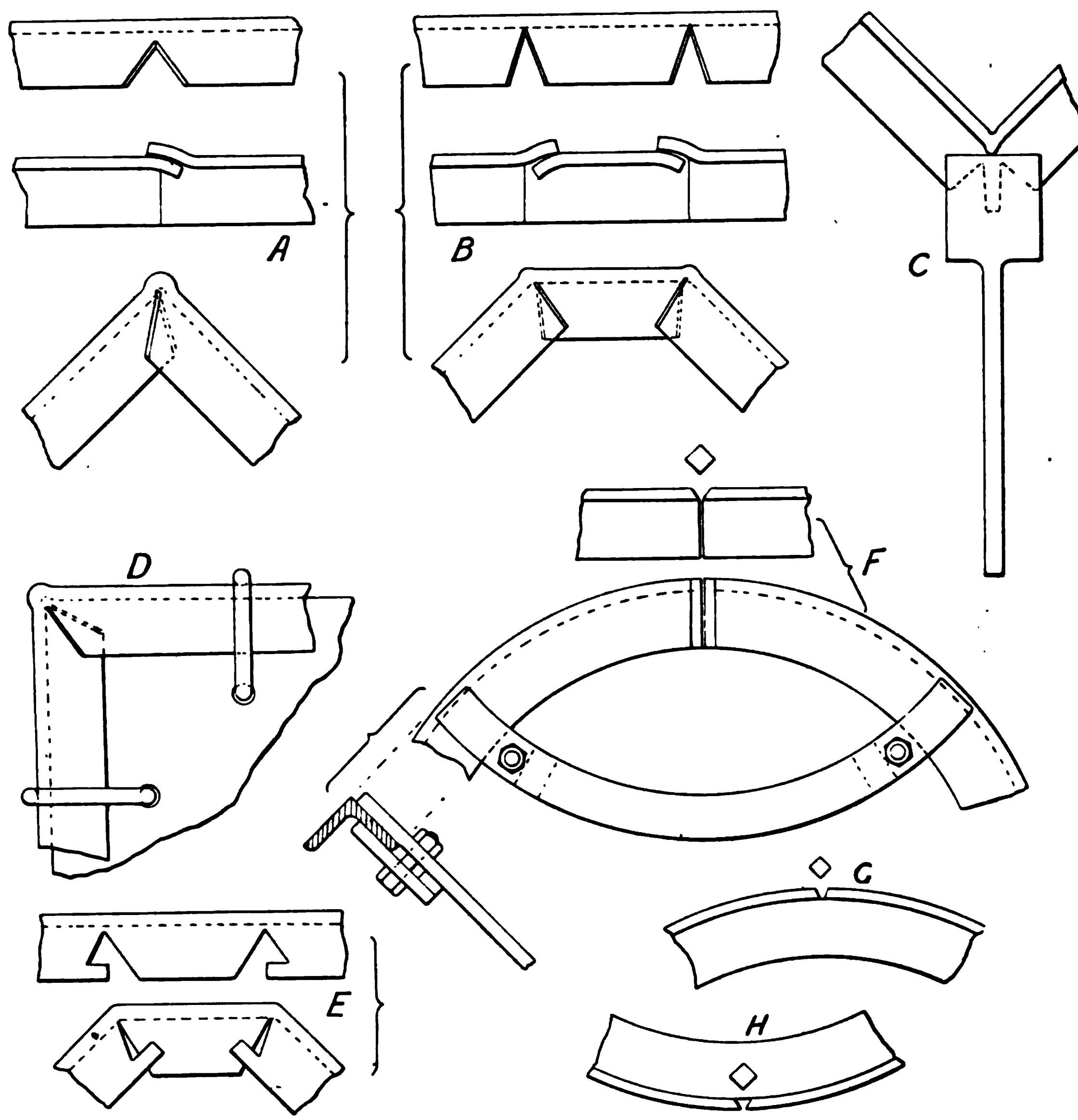

Fig. 85.—Methods of Making Welds.

A. Method of cutting, bending, and overlapping internal angle for making a lap or scarf joint. B. Ditto for two adjacent joints. C. Welding external angle, with middle tongue and glut piece, on porter bar. D. Internal angle clamped on block for welding. E. Alternative cutting for internal angle, with tongues, leaving open spaces to be filled with burrs welded in. F. Method of holding ring, while being glut-welded. G, H. External and internal Vee gluts.

the thinner sections, the former for the heavier, and this is used alone, or combined with a glut. The principal feature by which the welds of of puckering which takes place on the bending of a flange or web that lies flatwise.

If the web lies internally it will be crumpled

up badly. If externally, it will be stretched and attenuated. In neither case is a practicable result possible without making a weld in the flat web, though the vertical web is not in-

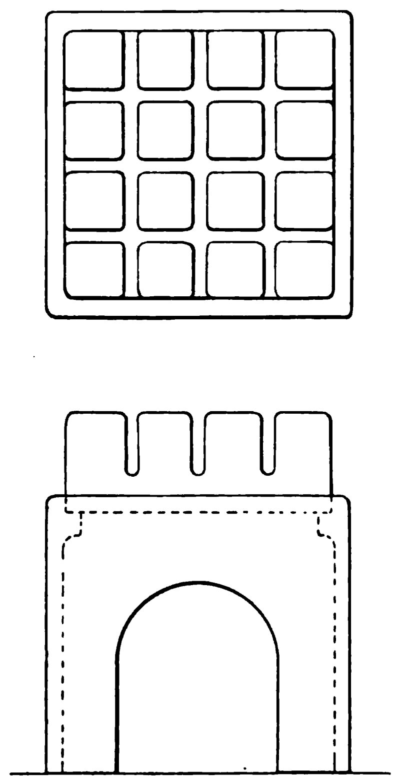

Fig. 86.—Block and Stand for Cutting and Dressing Angles and Tees, and other purposes.

cluded in this weld. But the metal here must be fullered, otherwise a good angular corner cannot be produced (Fig. 85, A, B, D). So that a weld in angle iron must be made as follows :—

The flat web must be severed at the portions which are to form the corners, and portions be cut out of a Vee shape. The vertical webs must be fullered. Then on bending the angle, an external flange will open at the corner, and an internal one will overlap. A glut piece will be welded in the first, and a scarf joint made of the second. A separate heat will have to be taken for this, in a hollow fire bricked over. After the weld is made, the fullering done to the vertical webs will afford metal for closing into a neat keen angle. At the time the welds are being made the angle is held in a strap of some kind. This general description covers numerous variations in detail relating to methods of overlapping, forms of gluts, and holding. *See* the details in Fig. 85.

Plain butt welds are generally distrusted, and therefore if a good scarf weld is not possible, or if that form is not desirable, the glut is used. Gluts are flat, or square, or triangular, or comprise combinations of triangles with flats. There is some very difficult work in this class of welding, due to the necessity for heating simultaneously the article to be welded, and the glut strip. Two forge fires are therefore often requisitioned, or preferably in some cases, as that of tubes, a portable coke or gas furnace is

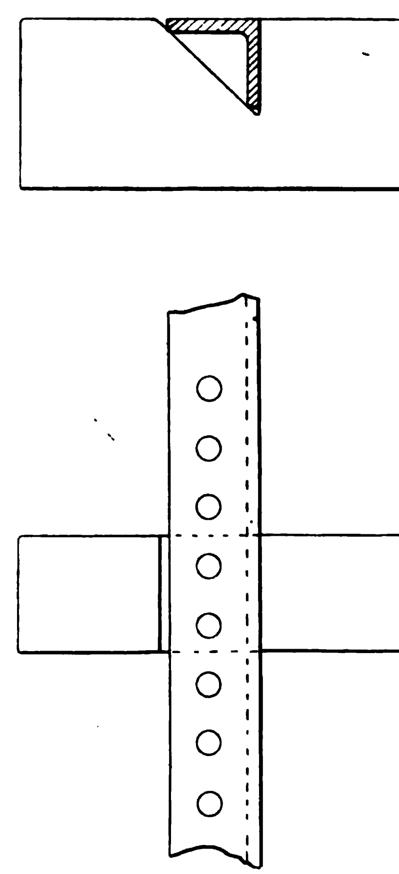

Fig. 87.—Angle laid in Vee Block for Marking Rivet Holes.

used, in conjunction also with a power welding hammer. When such welds exceed a few inches in length, they are done in detail in successive

heats, which again increases the difficulty and risk. In the case of welds of rectangular bars, two gluts are generally used, one on opposite sides. A good deal of dressing-off of ends of angles and tees is required in the foregoing operations. These are generally done on the cutting block shown in Fig. 86.

a good volume of work even in these shops, and the largest proportion, or the whole in the smaller shops, in which the methods of hand flanging must be adopted.

Flanging is more readily done now than formerly, because of the general substitution of steel for iron. The difference is that due to the greater ductility of steel, and the fact that there are no differences in the strength "lengthwise" and "crosswise," as there are in iron.

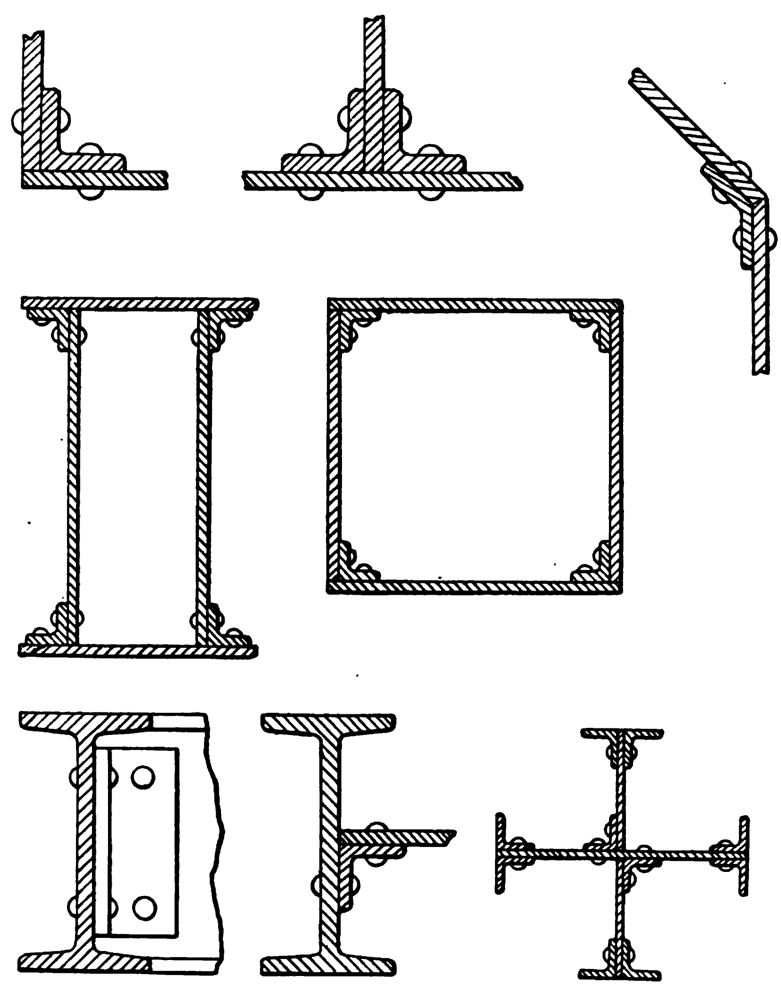

Fig. 88.—Typical Angle Joints, made with Angle-iron.

When rivet holes have to be marked on angles, the section is laid in a Vee block, Fig. 87, so bringing the face to be marked out, into a horizontal position, and holding it steadily.

Another branch of the work of the angle iron smith is flanging. In the large shops a great deal of this has been appropriated by the **Flanging Machines.** But there yet remains

Flanging is done when the edge must be turned with a considerable radius. If a square edge is wanted, that is not a case for flanging, but for union by means of angles. A notable illustration of this difference is seen in the end

plates of horizontal steam boilers, and the crowns of vertical boilers, once united to shells and flues with angle sections, but now universally flanged, with a radius of from 2 to 4 inches into the shell. Among the principal pieces of flanging done are these end plates and crowns, and the flanges of cross tubes, typical of other work for cylindrical vessels which have to stand pressure. The flanges of the tube plates and fire boxes of locomotive and portable boilers are seldom now done by hand flanging, but are stamped at one heat in dies in flanging machines.

Flanging, when done by hand, is an operation performed in detail in several successive heats. The ends of small marine boilers, though done in flanging machines, are also bent in detail in

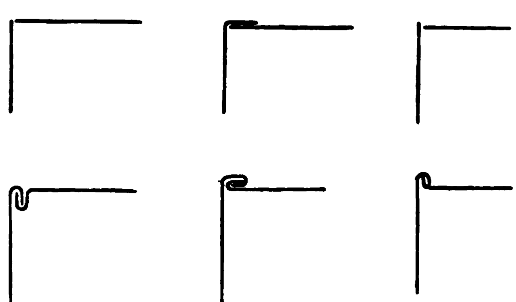

Fig. 89.—Typical Angle Joints, Plain and Seamed.

the largest work, because of the impossibility of taking a heat all round at once, and turning the large extent of edge at one operation. The subject will be found treated under **Flanging**.

Angle Joints.—These are joints made at right or other angles, without a radius, by the union of separate pieces, the union being effected by angle sections, or equivalent rolled sections which are riveted, in heavy plated work, or by seams and solder in the work of the coppersmith and tinsmith.

The union of plates and bars by means of angles and allied forms permit of the building up of many scores of different members in the shape of heavy columns, and other more complex constructional details. A few of these are shown in the group, Fig. 88, typical of a vast number of others. Angles unite other sections and plates. They form attachments for bracings; they are used to build up sections in place of using solid rolled sections, so lightening them; they form connections between joists.

In the simplest angle joints used by copper and tinsmiths, Fig. 89, the edges abut simply, and are secured by solder, either run along the inner or the outer edges. Abutting mitred joints are soldered or brazed. A stronger form is that where one sheet has an edge turned round, in which the adjacent sheet lies, and is soldered. The figures also illustrate lapping or seamed angle joints made by folding and closing edges one over the other, with the hammer, sometimes with, sometimes without the aid of solder.

The utilities of angle joints are great, but there are cases in which they are now inadmissible, as in the construction of steam boilers. In the old days of iron boilers, nearly all joints were absolutely angular, with the result that serious grooving, resulting in explosions, became frequent. But in the greater part of constructional work, angle joints are the best to use, hence the facilities which are afforded by angles, tees, channels, &c., for uniting plates and bars are taken full advantage of. The methods of riveting up these and other joints will be found treated under **Rivets, Riveting**.

Angle of Approach.—*See* **Arc of Contact.**

Angle of Friction.—*See* **Angle of Repose.**

Angle of Recess.—*See* **Arc of Contact.**

Angle of Lag.—*See* **Alternating Currents.**

Angle of Relief.—*See* **Angles of Cutting Tools.**

Angle of Repose.—The angle which the surface of a given material makes with the horizontal when a body is about to slide down it. It is also termed the angle of friction, and the limiting angle of resistance. *See* **Friction.**

Angle of Upset.—When a balance crane is being tested, the maximum load is lifted safely without blocking girders or rail clips so long as the lift is parallel with the line of rails, because the wheel base of the truck is amply long enough to ensure stability in that direction. If, however, the crane is slewed round to bring the axis of the jib at right angles with the track, it will not, in many cranes, lift the maximum load, because the base formed by the

wheel gauge is not wide enough, but the crane will upset, unless the truck is secured to the rails with clips, or blocking. Somewhere between these two extremes the balance begins to be unstable, and the angle which the jib makes with the truck in that position is the angle of upset for that crane, for its maximum, or any other load. If this angle is known for different loadings, it becomes a guide to the man in charge, as to what he can carry safely when away from the straightforward position, and when the clips or the blocking must be resorted to.

Angle Plate.—The angle plate (also termed angle chuck) is a bracket form of casting having two faces at right or other angles with each other, utilised in attaching work to, for various machining operations. It has a series of holes, or preferably slots, through which bolts are passed for the purpose of clamping, Fig. 90. The arrangement of these slots is widely varied in different plates, according to the ideas of the maker, but it is desirable that some of them should lie at right angles with the others, so that adjustments in both lateral directions can be effected when necessary. The two working faces which constitute the angles may be of equal width, or one may be considerably wider than the other, depending on the class of service required. The faces are planed or otherwise machined accurately, since on their precision the truth of the work produced depends. Very often, too, the back or inner surfaces are machined parallel with the front ones, so that objects can be clamped truly thereon, which is occasionally found necessary. Ribs or brackets are cast on all but the smallest plates, in order to stiffen them and prevent springing. These ribs may run in a straight line from corner to corner, or form only a radius, as in Fig. 90. The latter is not quite so strong as the former, but it stands out less in the way, and is therefore often preferred.

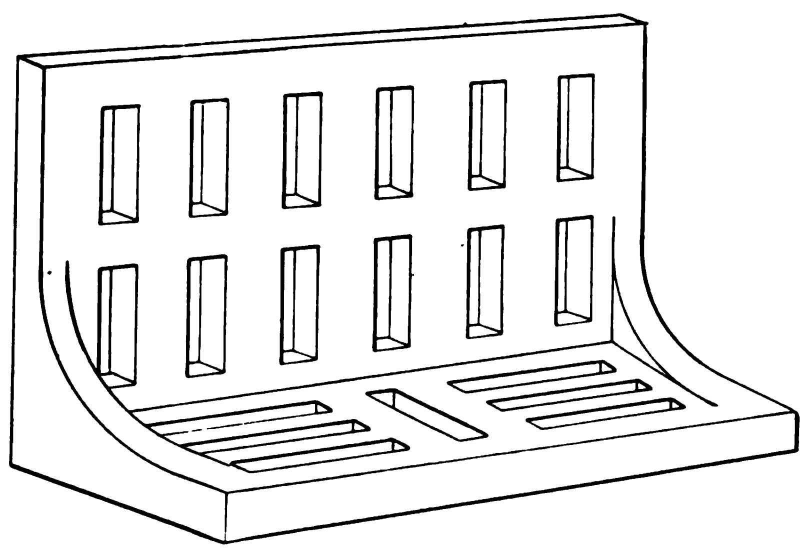
Fig. 90.—Angle Plate.

The dimensions of angle plates range from those of 3 or 4 inches in length up to several feet, according to the size of work to be done. A single plate will take a considerable range of objects bolted on in various ways, depending on the kind of job, and the class of operation to be performed.

Angle plates are used on turning lathes, planers, shapers, slotters, milling machines, drilling machines, and a few special types. In the case of lathes the angle plate is bolted to the face plate, and in the other machines upon their tables, the slots in the latter receiving the clamping bolts.

The primary function of an angle plate is

that of holding one face of an object which stands at right angles to another face, the latter being presented truly for machining thereby. Two purposes are thus served—the work is held accurately, without having to resort to measurements, such as squaring up, and convenience of clamping is secured. For example, a common globe valve is held best on an angle plate, Fig. 91; the alternative of packing up the job on its side, and testing and

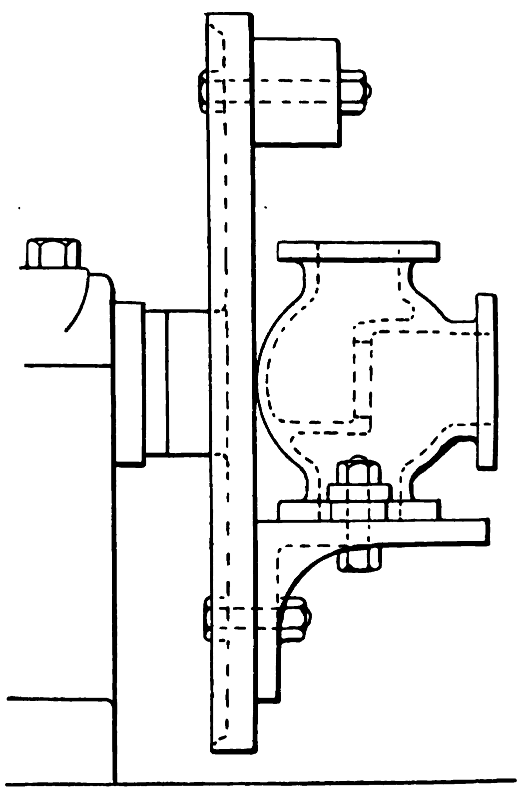

Fig. 91.—Angle Plate holding Valve or Cock Body on Face Plate of Lathe.

setting until it is found level and square, takes longer, and is not so certain as the angle plate method. The plate is therefore a great time-saver in the matter of clamping, enabling this to be done in a fraction of the time taken by tentative methods.

The faces of the work bolted down may be either rough or machined. If two surfaces have to be tooled in succession, one must be first clamped when rough, but this does not matter, because in turn the first machined face is gripped, and the rough face then trued up properly. If the rough part is too uneven to stand firmly, wedges or packing may have to be slipped under, just as in ordinary bolting down on machine tables. It may sometimes be found that the two angles to be machined are so much out of square with each other that packing must be used to average the inaccuracies; otherwise the metal will not "hold up" if tooling is continued until squareness is attained.

In many instances the comparatively small area of the angle plate is insufficient to carry the weight of a long or heavy piece, and supplementary support must be afforded by packing blocks, placed upon the machine table, taking the overhanging mass of the object held (*see* Fig. 92). In such a case the angle plate serves less as a support than as a controlling guide for angle, care being observed that the auxiliary

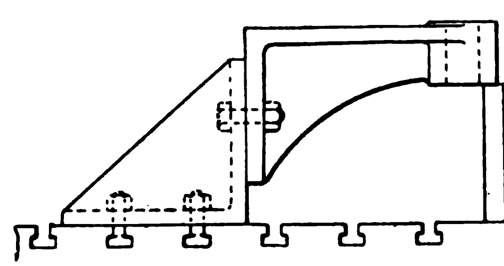

Fig. 92.—Work on Angle Plate, having Supplementary Support.

packing employed does not throw the job from its proper bearing on the plate. It is quite possible to spring a long piece in this manner by wedge or screw packing, so that the machined faces are not accurate when the work is released. Fig. 93 shows a cylinder on an angle plate, but the overhanging flange rests on the table also.

Occasionally two angle plates are used in conjunction upon a table, supporting both ends of a casting or forging, in cases where the piece cannot be fastened direct to the table, and one plate is not enough to sustain the weight. If two plates are also brought close together, they may be employed as a vice, gripping a thin strip or other piece between them, the drawing together being done by bolts.

Although angle plates are chiefly intended for holding pieces embodying definite angles, they are in many cases employed for clamping very irregularly shaped objects, not because certain angles are at once set truly, but because there is no other efficient way of gripping the work. Tentative setting has to be done, to bring certain portions into position for operating on them, the plate affording nothing more than a handy support. A large amount of work is held against the tables of drilling machines, and some others in this way, the plate providing simply an extra face which is absent in the machine table.

It is often possible to convert an angle plate into a sort of jig by attaching two or more stop blocks to the face, so that several pieces of work may be clamped down, one after another, in similar positions, to have tooling done upon them. The stop blocks serve as abutments, and ensure that the pieces will all occupy the same positions when fastened. Such blocks are also useful to take the strain of cutting, and prevent the work from shifting under pressure.

The angle plate is used extensively on the turning lathe, principally for holding work to be bored and faced. It would often be impossible to grip certain pieces without the aid of the plate; and in other cases, even where it might be dispensed with, the hold would not be secure enough to withstand heavy cutting. The possible alternative to the use of the plate is occasionally that of packing blocks, but these involve more work and time in chucking. When made specially for lathes, angle plates have one longitudinal edge curved, so that, as the face plate revolves, there are no sharp corners flying round, but the angle plate side corresponds in curvature to the periphery of the face plate. One side of the plate is also often wider than the other, the short side being bolted to the face plate, and the long side carrying the work. This is done because a very long side laying on the face plate would be of no use, but would hang out awkwardly, and be in the way. Another point which must be observed in face plate work is that of counter-balancing the weight of the angle plate, which lies to one side of the centre, and so throws extra weight to that side. This would result in jerky and uneven running unless the excess of mass were balanced approximately. This is done by bolting a lump of metal to the opposite side of the face plate, Fig. 91.

Although right angles are the most commonly incorporated in angle plates, special plates may be sometimes made embodying other angles, acute or obtuse, to suit the requirements of particular jobs. In repetition work these fixed angles enable large numbers of pieces to be machined alike, and the necessity for setting each piece is obviated. Adjustable angle plates are also made, having a hinged joint, and means of locking the faces at any desired angle. Additions are provided to angle plates in the form of pins or studs, to fit into holes in work, and partly hold the same, or retain it in a definite position. The studs may be often prolonged into screws, and used for bolting the work down, with or without the help of other clamping bolts.

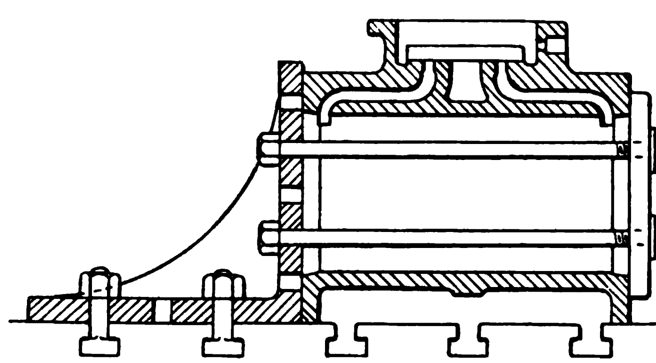

Fig. 93.—Angle Plate holding Cylinder for Planing, Shaping, or Milling.

The few typical illustrations of the uses of angle plates given are fairly representative of their various functions; these are modified in innumerable ways to suit work and modes of machining, but the principles remain the same.

Angle-Portal Crane (a literal rendering of the German, *Winkelportal Kran*, being the country where these cranes have been mostly

developed; also called Half-portal).—A form of portal, or gantry crane, the horizontal and vertical framings of which, making a right angle, permit of the passage of trucks beneath (*see* Fig. 94, Plate VI.). The vertical framing carries the ground wheels, while another set of wheels at the opposite end of the horizontal members runs on an elevated track, usually supported by the wall of a warehouse. The advantage is that one vertical framing is saved, with the space that it would occupy. *See* **Gantry Crane, Portal Crane.**

Angle Rolls, or **Angle Iron Rolls.**—The general section of these rolls for equal-sided angles is shown in Fig. 95, the points to note being the following:—

The angles lie so that both the flanges make equal slopes from the horizontal. In unequal-sided angles both flanges approximate to the same condition. This lessens the stress imposed on the metal by rolling, and favours free delivery. Angles are therefore more favourably shaped for rolling than some other sections, as channels, joists, and rails, in which some portions must stand perpendicularly, and be provided with draught, or bevel on inner faces, and in which also in some cases one section is considerably thicker than others, which increases the time occupied in rolling, and tends to produce curved and twisted bars. The design shown avoids the evil effects which result when there is considerable difference in the diameters of the rolls. When this happens, the larger radius moving at a higher velocity than the smaller, slides with much friction on the parts of the metal which it operates against, stressing the metal so that it twists and curls badly when it leaves the rolls. Further, the rolls are so shaped that the diameters are about equal at the edges of the rolls, which again is done to avoid risk of curling of the bar. Another thing is that the formation of fin is prevented by the close manner in which the rolls fit one another. Sometimes the angles are turned over for the finishing passes, in order to allow the scale to fall away, instead of being squeezed into the bars. Differences in the thicknesses of angles having the same width of legs are provided for by the open shoulders of the rolls, which permit of bringing the axes farther apart from each other.

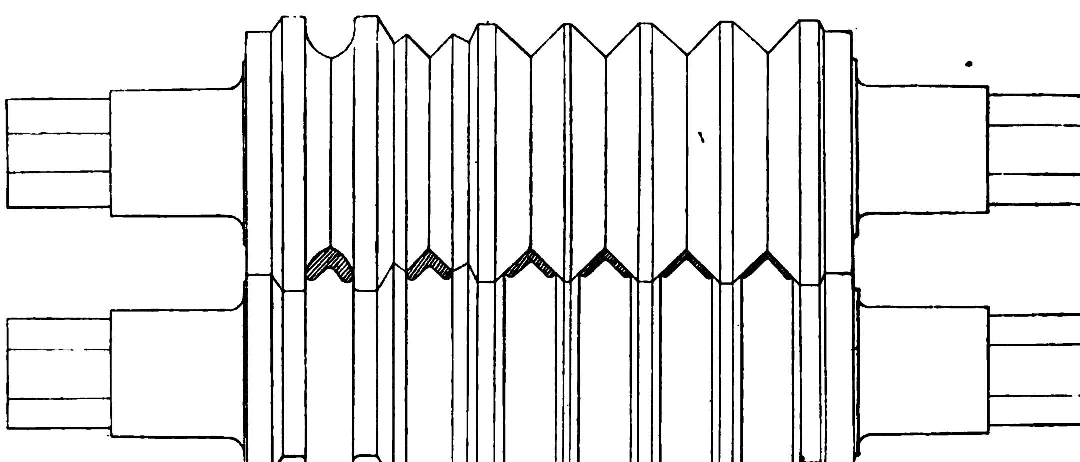

Fig. 95.—Angle-iron Rolls (9 in. mill) for Rolling Angles 1½ in. by 1½ in., from Billets 1¾ in. square.
(Thos. Perry & Son, Ltd., Bilston.)

Angles.—*See* **Angle, Angle Iron, Fillets, Protractor.**

Angles of Cutting Tools.—The wide subject of the various shapes of cutting tools will be found treated under that head. The present article has reference only to the particular angles which experience has demonstrated to yield the most efficient results.

The theories which have been formulated relating to the angles of cutting tools do not always harmonise with the practice of the shops.

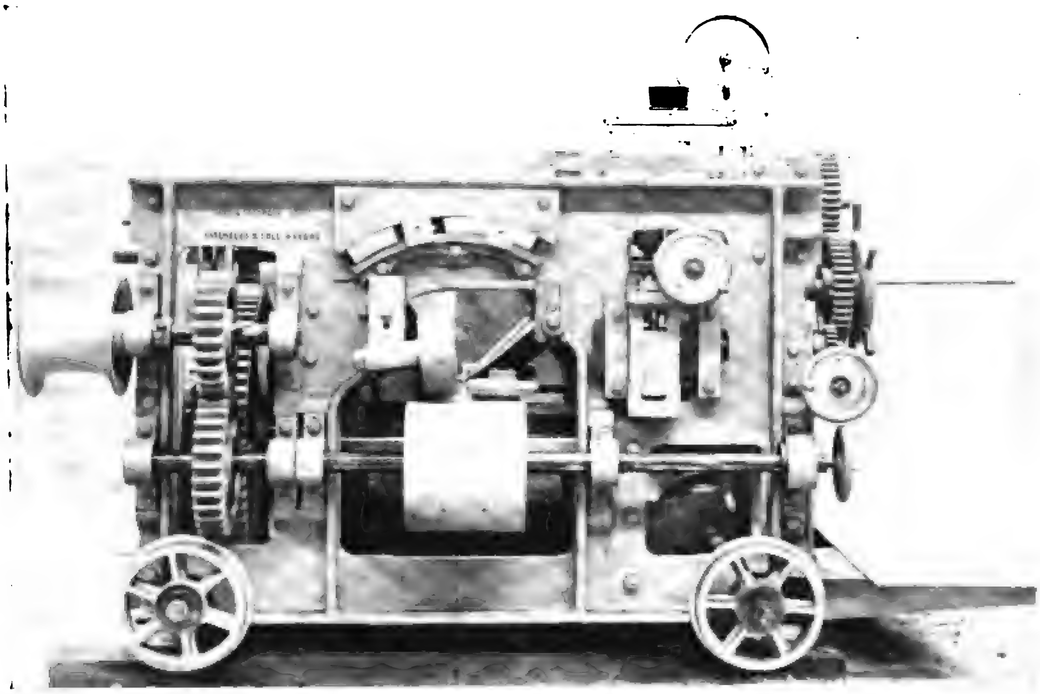

Fig. 69.—Bevelling Machine for Angles, and other Sections, up to 9 in. width of Flange.
(Davis & Primrose, Leith.)

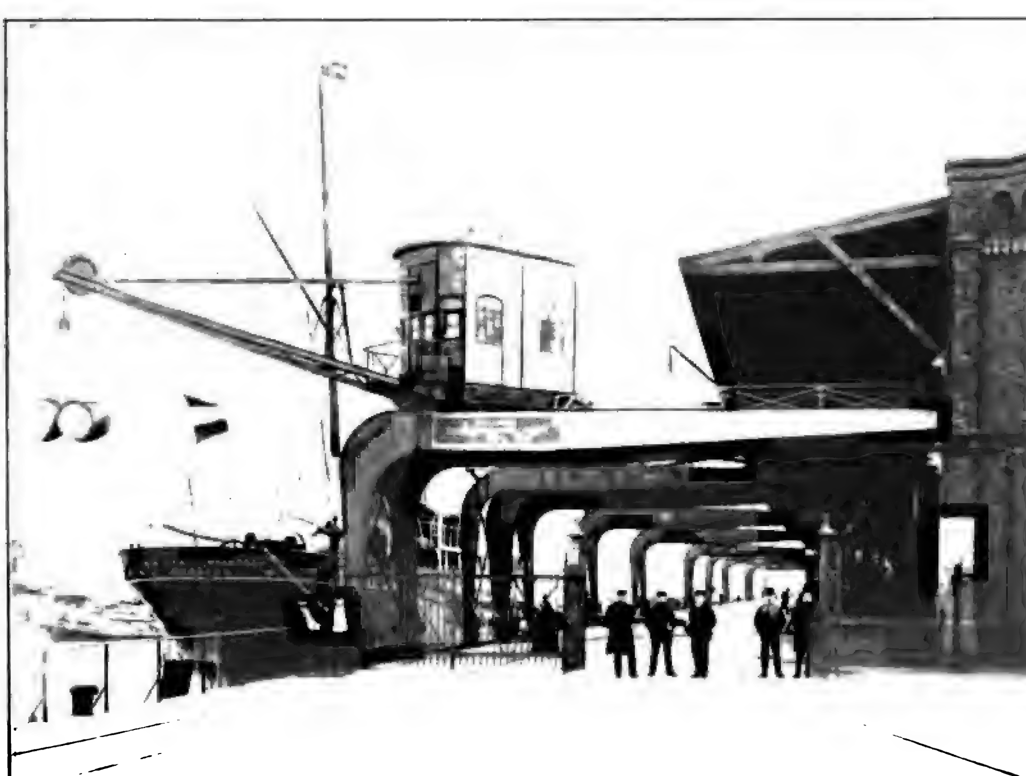

Fig. 94.—Electrically-driven Angle-Portal Crane, Hamburg.
(Allgemeine Elektricitäts-Gesellschaft, Berlin.)

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The fact remains that good practice presents many points of divergence which it is difficult to reconcile on the supposition that tool angles are governed by hard-and-fast conditions.

There are four essentials in the formation of any true cutting tool — penetrative capacity, adequate clearance, strength, and permanence. These vary with the nature of the material operated on, and the degree of hardness of the tool. The removal also of two obstructions to the good operation of such tools must be provided against, and are partly included in these conditions. One is the character of the chips or shavings cut, the other that of the lessening, and removal of the heat generated by the cutting. In the abstract these would appear easy of accomplishment. In practice they are subject to many variations in the hands of those who have to use the tools.

A cutting tool is a wedge. But a wedge is not always used as a cutting tool. Thus the axe, Fig. 96, A, is operating by splitting only when it cleaves the block. It cuts when it removes chips or shavings, as shown at the side B.

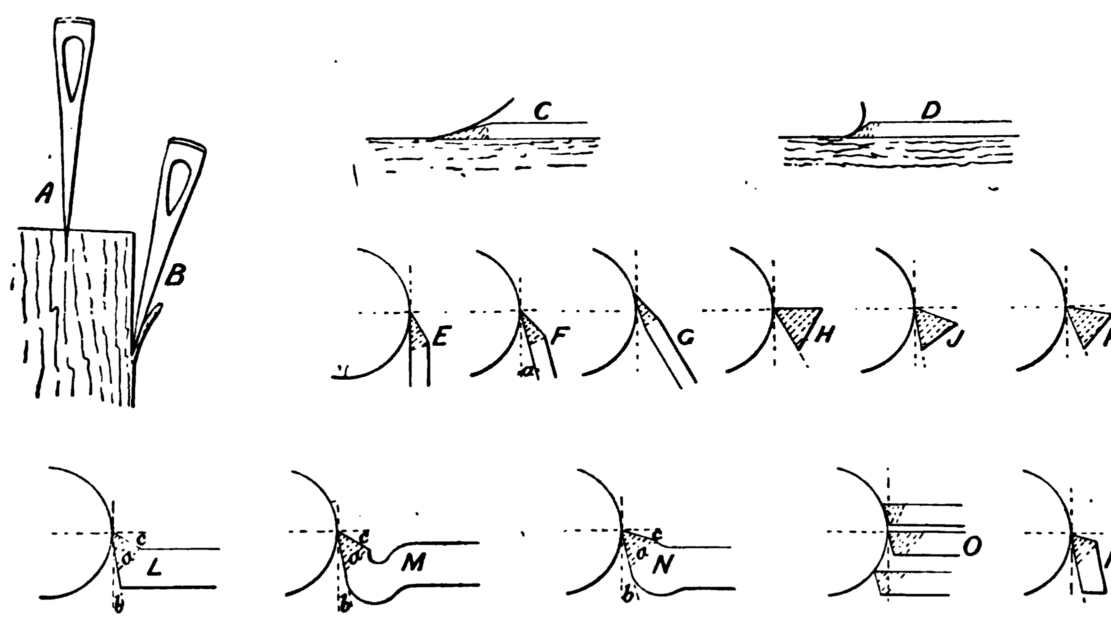

Fig. 96.—Angles of Cutting Tools.

A, *B*. **The axe splitting and cutting.** *C*, *D*. **Chisels with thin and thick angle.** *E*, *F*. **Chisel edge.** *G*. **Side chisel.** *H-K*. **Different presentations of the graver.** *L-N*. **Common lathe and planer tools.** *O*. **Different presentations of the same tool.** *P*. **Knife tool.**

One may learn a very great deal about the action of cutting tools from the wood-worker's chisel. It is a keen-edged instrument which cannot be sharpened much too keenly for soft wood, for which a cutting angle of from 15 to 25 degrees is suitable. Clearance between the face of the chisel and the wood is practically nothing. If, however, this thin chisel is used on a piece of lignum vitæ, or greenheart, or of soft copper, its edge will turn over, and be destroyed, for the simple reason that it lacks the necessary strength, and the tool angle must therefore be increased. Taking two such chisels, let one be ground as represented at C, or say to an angle of about 15 degrees, and the other as shown at D, or to an angle of about 30 degrees, and let them both be sharpened similarly upon a hone. Now try them each in succession on a piece of soft end-grain timber, and the result will be that C will cut sweetly, and D only do so with difficulty; C will remove a nicely curled and clean unbroken shaving or chip, while D will only remove small fragments, by a process which is more akin to tearing than cutting. Moreover, a very much

greater expenditure of muscular effort will be necessary to actuate the last named than the second.

Following the chisel into other forms, as a simple method of grasping principles:—Imagine a chisel end supported on a rest, and power operated, as at E, in a position for removing material from the flat piece of wood (or metal) indicated by the dotted line, or from a circular piece, as in the lathe (full line). The objection to the position of E, when cutting metal, is that too much friction is set up between the chisel face and the face of the work. In C and D, being hand-operated chisels, this is of no importance; in fact, the control which the face of the work affords to the chisel is a necessary aid to true cutting. But that reason no longer exists in machine-operated tools, hence the tilting of the imaginary chisel as at F, gives clearance at *a*, which avoids undue friction, with its resulting waste of power. Even in turning wood by hand the workman instinctively tilts the side chisel a little, G, to lessen its frictional contact with the work.

Going a stage farther, take the graver, a hand tool of triangular ection used for turning metal. It is in principle a chisel point, as a comparison with the shaded areas in C, D, E, F, will show. Presented as at H it does not act as a true cutting tool. At J its action is almost identical with that of the chisel E, or F, but at K it resembles more that of a tool for turning cast iron. In each case the angle of the tool itself remains unaltered, but the methods of presentation differ, so that the clearances vary, and so does the slope of the top face, or the "top rake."

We are now able to trace the subject a stage farther. Evidently there are three elements involved, the tool angles themselves, the angle of front rake, or relief, or clearance, and that of top rake, or slope, each of which is subject to considerable variations.

To cut the hard metals and alloys the tool angle must be much greater than that of the soft wood chisel, the keenness of the wedge being sacrificed to strength; penetrative power being therefore less, and permanence greater. Front clearance too, the amount of which is a matter of little or no moment in wood cutting, is a highly important factor, essential in cutting metal, being necessary in order to diminish the heat generated by the friction of metallic surfaces. There are thus a number of opposing and contradictory conditions to be observed in the formation of any cutting tool, and because of this no rigid set of rules can be possible.

Since the mode of presentation of the tool to the work is of as much importance as the cutting angle itself, there are thus two conditions which are of a fundamental character. The aim should be to obtain as close an approximation to these as possible, consistently with the conditions imposed by the character of the material being operated upon. These are the following:—That the top, or cutting face of the tool shall make the smallest angle practicable with the face of the material being cut, or in other words shall approach the tangential line. Also that the largest amount of material possible shall be massed immediately behind the cutting edge in the direction of the line of thrust of the work. As the fulfilment of these leaves little angle between the front face and the face of the material being cut, the conclusion arrived at is that the minimum angle of relief should be settled first of all, and the others be afterwards fixed. These are of the nature of axioms, to which there are no exceptions. Whatever the types of cutting tools, we find that these principles have their application therein.

The graver, and the old heel tool, once common in engineers' shops, depended for their best results upon the way in which they were manipulated by the turner. They were ground to constant cutting angles—about 60 degrees—but were made to cut all metals and alloys, and both roughed and finished, simply by varying the method of presentation. This variation being impracticable in the slide lathe, the settlement of suitable angles for the different tools which are fixed is an important problem.

L, M, and N illustrate three common forms of lathe (or planer) tools, in which areas are shaded in order to illustrate the relation of such tools to the graver and the chisel. The only difference lies in the shape of the tools as forged, and not necessarily in angle, since each of the three forms has its angles varied for different materials.

The standard tools which have been evolved

from these are made in three different angles for wrought iron, and soft steel, cast iron, and cast steel, or tough qualities of mild steel, and those for brass. Similar angles are adopted, whether the tools operate on a circular or on a flat surface. In each case there is the tool angle *a*, which is the element that confers strength; the front clearance angle, or angle of relief *b*, that reduces friction; and the angle of top rake *c*, which, taken in conjunction with the tool angle, affords penetrative power, and provides for the removal of the cuttings with as much facility as is consistent with the necessary conditions of strength.

The angle of relief *b* is sometimes as low as 3 deg.; 5 deg. is common. The latter need not be exceeded in cases where a large tool angle is desirable, as for working on hard and tough materials. In softer materials, such as wrought iron and brass, it is frequently 10 deg., and even more. The tool angle *a* ranges from about 50 deg. for wrought iron, to 60 and 70 deg. for cast iron, up to 80 deg. for very tough materials, and for brass.

These angles, though considered standard, are so in a general sense only. For example, the tool angle *a* can be diminished with advantage in the turning of very soft samples of metal, so giving greater penetrative capacity, increasing bottom clearance, and the angle of top rake, each of which lessens the tendency to heating. In working good tough gun-metal, top rake is imparted with advantage, though the ordinary brass-turning tool has none. For turning hard, harsh iron, or steel, whether wrought or cast, the tool angles are increased with advantage. It is then desirable to maintain the top rake intact, and to reduce the bottom rake to a mere trifle. The reason is that the tougher or less crystalline the metal or alloy being turned, the greater need is there to give the shavings some chance to come away in a regular curve, instead of abruptly. There will be less strain, less heating, and a heavier feed can be taken under the first conditions than under the second, in which the work of breaking up the chips on the tool point is added to the legitimate work of cutting. In crystalline metals, such as cast iron, and in hard brass, the top rake is diminished by comparison with that for fibrous metals, because the nature of the material favours its rapid breaking up into short chips, and for that reason the angle of top rake is less than in tools cutting wrought iron and soft steel.

The greatest power which is absorbed by cutting tools is that required for severing, and breaking up the chips, and to this the principal attention is given, and by it the angle of the tool is governed, a low keen angle only being given for soft materials, which grows gradually higher as metals and alloys increase in hardness and toughness. A stiff chip offers a great amount of resistance, and therefore absorbs power. The aim, therefore, is to so shape a tool that the cuttings shall come off as shavings, instead of in short broken chips. The top face of the tool must therefore have a long easy slope instead of an almost normal relation to the face of the surface being cut. This is the reason for the statement made just now, that the face of the tool shall make the smallest angle practicable with the face of the material being cut. The limit to the slope is the weakness of the tool angle, and the limitation imposed by the fact that a tool too keen has a tendency to be drawn into the work, or to be "proud," and chatter. But this again is to some extent controlled by the general formation of the tool, and the manner in which it is held. A good example is that a tool suitable for wrought iron, will if held stiffly and well cranked, rough down gun-metal more rapidly than the common brass-turning tool will do it.

These remarks apply most forcibly to actual cutting, meaning by that the removal of material in quantity by an incisive or penetrating action, ranging from say $\frac{1}{16}$ to $\frac{1}{2}$ inch deep, denominated roughing cuts. The case is rather different in the finishing or scraping cuts. In these the penetrative action is so slight, and the quantity of material removed is so small, that there is little or no curling of the shavings, and top rake is unnecessary, except in so far as it gives a keen tool angle. Actually finishing tools are made, as regards cutting angle, in any range from that of the roughing tools, to that of the tools for brass. This is a point which it is well to bear in mind, since it will explain the use of several tools which are made with little, sometimes with no top rake at all, and yet which are

capable of turning out a large quantity of light work.

In the formation of a large number of special tools which are used on turret lathes, it is obvious that it would be highly inconvenient to grind top rake, and therefore it would seem as if the principle of true cutting by incisive penetration must be abandoned for mere scraping. This is true in some cases, but even in these there are special arrangements introduced which more than compensate for any loss due to unsuitable tool angle. In other cases, however, what is lost in actual form is partly gained by method of presentation. Thus in Fig. 96, O, it is obvious that the one tool presented at O, that is normal to the work, which is the orthodox mode of presentation, will act only as a scraping tool. If presented above, or in advance of the centre, it becomes an incisive tool, precisely as though top rake were ground upon it, and the chips will curl off its surface. On the other hand, the presentation below the centre would be the worst possible, absolutely wrong in theory and in practice. The device, therefore, of setting the tool ahead of the centre is very generally adopted in the case of turning, and also of chasing tools in which it is desirable to avoid having to grind top rake on them. Most of the special tools used in turret work are ground to profile form by gauge in the first place, and are not touched afterwards, and all future sharpening is done by grinding the flat faces and not the profiles. In this way the forms are retained for a long time, and rake is imparted not by grinding, but by the method of setting. P shows a side tool or knife tool, with top rake, used for general lathe, and turret work, a form which is easily ground.

The endeavour is now made in many shops to give to all tools, no matter which type of machine they are used upon, the angle which experience has settled as the most suitable on the whole for any given kind of material, disregarding the infinite shades of difference in materials of the same name. Within a few degrees those angles are fixed, and adhered to by the grinders. The reason why differences of a few degrees of tool angle exist in the practice of different men and of different shops are these:—First, differences in the texture and hardness of metal of the same name, differences which are very wide, varying from relative softness to relative hardness, and harshness, and often amounting perhaps to 50 per cent. Second, variations in conditions of working, as for example that due to fine cutting, or to heavy cutting. For the first, the tool may be keener than for the second. Or variations in duration of cut, since it is desirable in some classes of work not to remove the tool for regrinding until after the cutting is finished, in which case some keenness is sacrificed to durability of edge. Third, in most modern shops the practice is followed of grinding all tools of the same kind to certain fixed angles in a tool-room, and handing them out to the men at the lathes and machines. In that case, there being no variation possible, an average angle is struck which is not the best for every class of work done, but the best on the whole for all classes of work.

The present tendency is therefore inevitably in the direction of the simplification of the angles of cutting tools. It harmonises with the necessity for constant reduction of the cost of production. The simpler a tool can be made, the less it costs for forging, and grinding, and the less for attendance. One great objection to the employment of turret lathes for general shop work is the cost of making and fixing up the boxes of tools which render turret work uneconomical for small numbers of similar pieces. This objection is being met by the use of simple tools, until in the later turret work many of the turning tools are simply pieces of flat steel bars requiring no forging, and only one angle has to be ground. In some cases the angle for top rake is embodied in the tool-holder, the insertion of a wedge-shaped slip canting the tool to the angle required.

The wider subject of the forms of tools in plan will be considered under the general head of **Cutting Tools**, as these are distinct from the cutting angles. Many tools have no true cutting angles, in which case they belong to the group of **Scraping Tools**. Many of these, however, are classed as cutting tools, because for various reasons they operate in effect by cutting, though not so in strictness of language.

Angle Valve.—A valve of the sluice type which differs from the ordinary in having its flanges at a right angle instead of with faces parallel. The horizontal flange is at the termination of a bend coming downwards from the body.

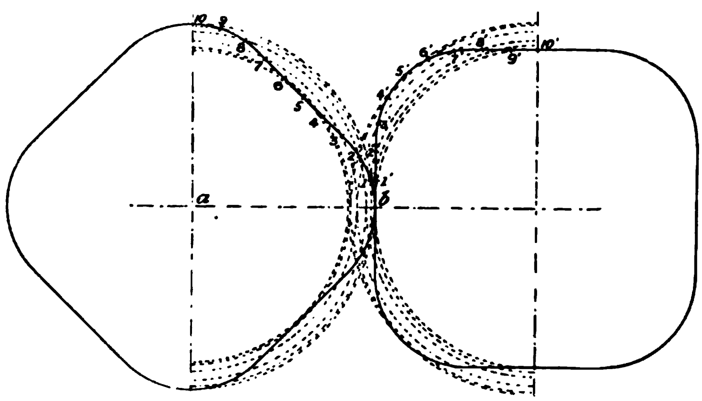

Fig. 97.—Illustrates the Development of the Pitch Lines of Square Gears.

Angle Wheels.—A term sometimes applied to **Spiral Gears**.

Angular Acceleration signifies the rate of change in angular velocity which occurs in a body rotating about a centre. Problems arising under this head occur in the fly-wheel and the connecting rod.

Angular Brace.—*See* **Brace.**

Angular Cutters.—Milling cutters which have two cutting surfaces set at an acute angle, designed for milling grooves of the opposite form, and for producing the teeth of cutters. *See* **Milling Cutters.**

Angular Fence.—Denotes a form of fence used on the benches of circular saws, which is capable of angular adjustment for bevel sawing. *See* **Saw Fence.**

Angular Gearing.—This denotes special forms of toothed wheels by means of which a shaft rotating at a uniform speed will transmit certain variable, but regularly alternating motions ranging between maximum and minimum. The forms in which this occurs are the square and the triangular, Figs. 97 and 98. Though so termed, they are not absolutely square, or triangular, since such forms would be impracticable, but the corners are made with some convexity. It is also essential, in order to avoid slip, that the wheels be of equal size (though not necessarily of the same shape). That is, the total length of the pitch lines or pitch planes must be equal if uniform rates of maximum to minimum are to be obtained. But if this is observed, the profiles may be complementary one to the other, as convex and straight, or concave and convex, &c., these variations being disguises of the square or triangular gears.

In the square gears, the corners must be rounded with a radius, equal to half the radius *ab* of the sides, Fig. 97. If the sides of the wheels were hollowed, then the radius of the corners would be lessened in proportion, and the lengths extended. Triangular wheels, Fig. 98,

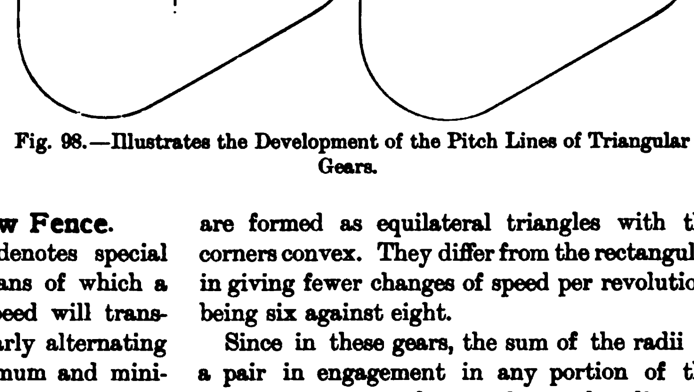

Fig. 98.—Illustrates the Development of the Pitch Lines of Triangular Gears.

are formed as equilateral triangles with the corners convex. They differ from the rectangular in giving fewer changes of speed per revolution, being six against eight.

Since in these gears, the sum of the radii of a pair in engagement in any portion of the engagement must be equal to the distance

between the centres of the gears, this indicates the method by which the various velocity ratios for the different positions are obtainable. It also gives the principle on which one wheel can be made to engage with another of predetermined outline. If the periphery of the latter is divided into any convenient number of equal parts, 1, 2, 3, 4, &c., circle arcs struck from the centre of the gear through those points of division will represent the positions which those points will assume in succession. Now from the centre of the wheel designed to engage with this, draw circle arcs starting from the line of centres and lay off lengths thereon, 1′, 2′, 3′, 4′, &c., equal to those on the existing wheel, Figs. 97 and 98. A line drawn through these will be the pitch line of the mating wheel.

The marking out of the tooth forms is not uniform for all the teeth, as it is in the case of circular gears, but every different circle arc requires a different shape of tooth, which again differs from the shapes of the teeth on straight portions, the latter being rack teeth. Another thing is that the teeth are usually made longer than the normal, because the teeth tend momentarily to separate as the corners begin to recede from the sides.

Angular-Hole Drilling.—The production of holes of square or other geometrical forms with a drill is a peculiar machine shop operation which has its applications chiefly in those cases where **Drifting** (or **Broaching**) is undesirable or impossible. Thoroughfare holes can be formed by the use of a drift, or broach forced through, a round hole being first provided, so that the drifting tool has to shape the angular portions only. This method is fairly accurate and neat, but cannot be so readily applied to blind holes,

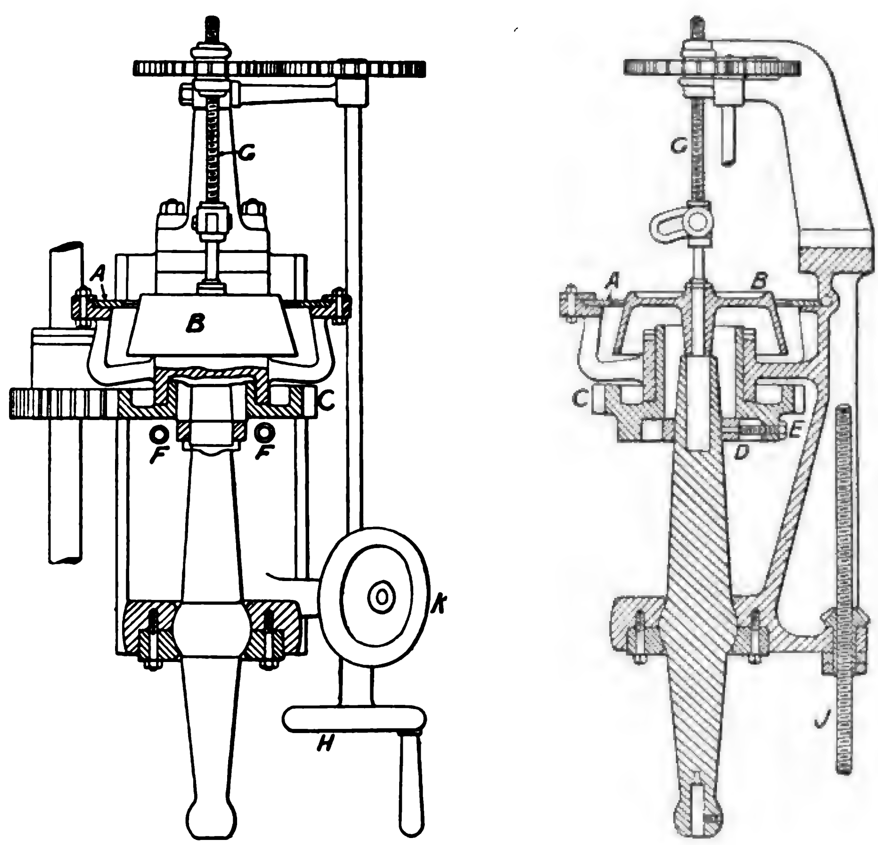

Fig. 99.—Mechanism of Angular-Hole Drilling Machine.

where there is no space for the drift to pass through. The alternative in this case is either cutting out laboriously with chisel and file, or forging, neither of which methods are very accurate. The difficulties of making a drilling tool travel around a hole into angles, with accuracy and freedom from chatter, are obvious, but they have been overcome in several devices. The principle in these is that of having a former, or templet, or cam, which controls and guides the cutting tool in the desired paths. The simplest device is that of coercing the drilling spindle by a former of the shape desired, either square, hexagon, octagon or otherwise.

This principle is employed in the machines of the Angular-Hole Drilling & Manufacturing Co., Ltd., of Beeston, by which the firm produces a variety of articles having angular holes, such as spanners of all kinds, handles, handwheels, and similar appliances. The process is specially valuable for shaping box spanners, which being blank ended, are not otherwise readily produced, except by forging, a rougher and less accurate method.

The essential mechanism of the machine is shown in Fig. 99, giving side and front part-sections of the drilling head, which is arranged upon a vertical framing similarly to ordinary drilling machines. It will be seen that the spindle differs essentially from that of a plain drilling machine, in being provided with a globular portion, which works in a socket, fitted with a retaining cap. The object of this ball and socket bearing is to allow of the spindle being worked round freely in a path corresponding with the shape of hole to be cut, this wabbling motion being imparted by the mechanism at the top of the spindle. The templet, or former, A, is attached with clips to a frame about the spindle, and inside this former lies a roller B, carried upon an extension of the spindle. The driving of the spindle is effected through the spur wheel C, which has a block sliding in it, and embracing the spindle, so allowing of the requisite amount of play. The set screw E is provided for setting the spindle centrally, for drilling ordinary holes if required. To cause the spindle, and consequently the roller B to follow the contour of the former A, two springs, F, F, are employed, which draw the slide D out of centre, so that the roller runs against the sides of the former and imparts the necessary wabbling motion to the spindle. To get varying sizes of holes, the screw G is provided, actuated through the handwheel and spur wheels. The end of the screw is freely connected to the roller spindle, so that the roller can be raised or lowered, bringing a greater or lesser diameter into contact with the former, and lessening or increasing the throw of the spindle. The function of the screw J is simply to raise or

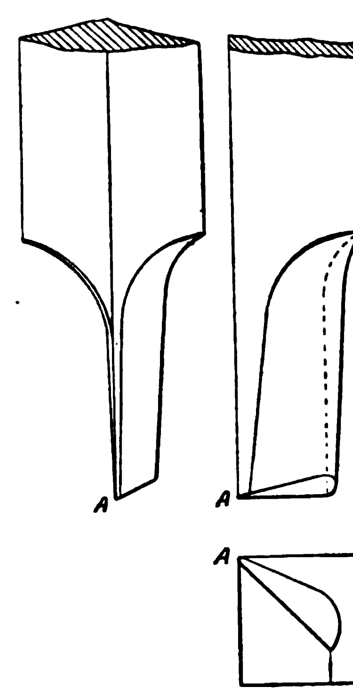

Fig. 100.—Tool for Drilling Angular Holes.

lower the entire slide carrying the spindle and mechanism upon the frame of the machine, this being accomplished by the handwheel K, acting through bevel wheels; or a power feed is given by feeding arrangements driving to the lower end of the screw, as in ordinary practice.

The cutting tool employed is of peculiar form, *see* Fig. 100, and attached to the spindle end so that its cutting edge is in line with the centre line of the spindle. As the latter moves around in its path, guided by the former, the edge A of

the tool runs into each corner of the work, finishing it out sharply. The operation is necessarily slower than ordinary drilling.

Tapered holes may be cut by manipulating the handwheel H, Fig. 99, which adjusts the roller B up or down, so that the throw of the cutter is increased or lessened.

Angular-hole drilling tools have been devised by various experimenters, in which, however, the principle is that of a former controlling the cutting tool. One such device embodies the use of a cutting tool of equilateral form, working by its end and a part of the way up its edges. This tool is coerced by a square hole in a former fastened just above the hole to be drilled, the drill being attached loosely to the spindle in "floating reamer" fashion. This simple method is interesting, because it can be applied without having to rig up expensive mechanism, and is very suitable for small holes. The accuracy of results depends on the truth of former and cutter; the former should be hardened, and of course the drill will be tempered, so that wear will be delayed.

In all cases of angular-hole drilling a starting circular hole is first put in, which may be deeper, or of the same depth as the finished angular hole is to be. In the case of box spanners and similar blank-ended objects, the preliminary hole may be a trifle deeper than the angular one will run to,—thus facilitating the operation of the angular drill, slightly; but the chief reason is that of allowing clearance for the end of the screw or bolt as it projects from the face of the nut. *See also* **Hollow Chisel, for Wood.**

Angularity of Connecting Rod.—*See* **Connecting Rod.**

Angular Milling.—This is done by two methods, either by using a cutter the section of which is angular, or by setting the work to the angle required, employing an ordinary edge, or face cutter. The first is generally the proper method to adopt when milling grooves, the second for external edges. In doing grooves the cutting usually includes bottom as well as edges, which renders the use of an angular cutter economical, and practically essential. In doing outside work it is often just as easy to tilt the work or the cutter holder as to use an angular cutter. *See* **Milling, Milling Cutters.**

Angular Threads.—Screw threads the sides of which subtend an acute angle. Distinguished thus from square threads. *See* **Screw Threads.**

Angular Velocity is the velocity of any body around a fixed point, whether it revolves like a crank-pin or swings backwards and forwards through an arc of a circle like a pendulum. Obviously, several different units of angular motion might be conveniently used—the movement through one degree; a single revolution; or the motion during a second or a minute. In practice, however, it is found convenient to adopt two units. The first and perhaps the most widely used unit is one revolution in one unit of time. The unit of time generally adopted in mechanics is a second, but in this case the minute is the unit of time. Measured by this unit a spindle revolving once in a second or 60 times in a minute would be said to have an angular velocity of 60. The second unit used in measuring angular velocity is an angle of 57·32 degrees—the number of degrees contained in an angle which subtends an arc equal to its radius. Thus the unit may be defined as "the angle subtended by an arc of the same length as its radius." This would be equal to $\frac{360}{2\pi}$ or the number of degrees stated above.

Angus-Smith Coating.—This denotes a mixture which is applied to the protection of cast-iron pipes to prevent their corrosion. It is composed of 1 part of coal-tar to 3 parts of pitch oil, heated to the boiling point of the oil, from 350° to 450° Fahr., and the castings are immersed in it, and allowed to remain until they become of the same temperature as the mixture. They are then withdrawn, when the naphtha and other volatile oils evaporate, leaving a firm hard coating of pitch adherent to the pipes.

Anhydrous.—A term used in chemistry to signify a substance having no water in its composition. Quicklime, CaO, is anhydrous when it leaves the kiln. But immediately water is added, an augmentation of bulk occurs, the water combining with CaO to form the

white dry powder known as slaked lime, or hydrate of lime, $CaOH_2O$. An everyday example of the process of changing an anhydrous into a hydrated substance is seen in the use of Plaster of Paris. This is prepared by heating gypsum ($CaSO_4H_2O$) in a kiln at a temperature of 250° Fahr. The water is driven off, leaving $CaSO_4$. It readily recombines with water, however, and at once solidifies—a property which makes it so valuable in various industrial arts.

Anhydrous Tar.—This is used in lining the **Bessemer Converter**.

Animal Charcoal or bone-black is obtained by heating bones in closed retorts. When the process is completed there remain 10 parts of pure carbon, 88 parts of calcium phosphate, and 2 parts of other salts. Enormous quantities of bone-black are used in sugar refineries owing to its peculiar power of decolourising syrups. The animal charcoal is placed in large iron cylinders to a depth of 10 to 40 feet, and the coloured syrup gradually gravitates through the mass, issuing quite colourless.

This decolourising property of animal charcoal is possessed not so much by the 10 per cent. of carbon contained in it as by the calcium phosphate, for if the latter be dissolved out of any given quantity the remaining carbon is found to have but one-third of the decolourising power possessed by the original mass.

After a little use the pores of the charcoal become clogged, and it ceases to act. It is then revivified by washing and reheating, this operation being repeated as many as a hundred times in a sugar refinery.

Bone-black is also used in water filters, and for absorbing various substances held in solution. Its use as a powerful deodoriser is well known.

Animal charcoal is used by engineers and smiths for **Case-hardening** processes.

Animal Oils.—*See* **Oils.**

Animal Power.—The power of animals, including that of men, is of less importance than formerly in civilised countries, in consequence of the growth of machinery and self-propelled vehicles. But it is yet the only power available in semi-civilised lands, in which goods have to be carried, or hauled over plains, and mountainous districts, as well as in many other out-of-the-way parts.

There is much uncertainty in statements made respecting the power of men and animals, due to differences in individuals, and the methods in which power is applied, and in the conditions under which experiments and observations have been made. But if taken as approximate guides, the following express the general facts regarding these :—

In estimating the power of animals, the force exerted depends greatly upon the attitude in which the work is done. A horse moving in a circle, and turning gear for pumps, &c., does not labour to so much advantage as when hauling on a rope straight forward. And the smaller the circle, the less is the efficiency. A man pushing a winch handle downwards brings the weight of the upper part of his body to bear upon it, but in the upward pull he is at a disadvantage. And the period during which force is exercised is a great factor, as is also the number, and length of intervals for rest.

Horse Power.—Watt estimated the power of a strong horse at 33,000 foot pounds per minute, and made that the basis on which to sell his engines. This is too high for the continuous work of a strong horse, and the power of an average animal cannot be estimated above 22,000 foot pounds per minute.

The method in which the power of a horse is best exerted is in the form of **Traction**, either pulling a vehicle along, or less efficiently, turning **Horse Gear** in a circular path. On a level, and on a fairly smooth road, the tractive power of a horse is 100 lb. at a rate of 2½ miles an hour for 10 hours—a total of 13,200,000 foot pounds per day. As the amount of a day's work remains constant, either the horse's power, or the speed can be increased for a shorter period. That is, his tractive power in pounds will be greater if the hours of work are lessened; or his speed in miles be increased if the hours of work are lessened, or if the tractive work is diminished. But if the horse is operating gear, the day's output will not total to the 13,200,000 foot pounds stated, but less, the amount of which will depend on the power lost in the friction of the machinery operated.

The tractive force of horses varies according to different observers, thus :—

Rate in Miles per Hour	1	2	3	4
Tractive Force in Pounds	250	125 to 166	83 to 125	83 to 62

Desaguliers stated that a horse employed daily in drawing nearly horizontally can move during an eight hours' day about 200 lb. at the rate of 2½ miles an hour. Tredgold estimated the maximum quantity of labour a horse of average strength was capable of performing at different velocities on canals, railways, and turnpike roads as follows :—

Velocity in Miles per Hour.	Duration of the Day's Work at the preceding Velocity.	Force of Traction in Pounds.	Useful Effect of 1 Horse working 1 Day in Tons drawn 1 Mile.		
			On a Canal.	On a Level Railway.	On a Good Level Turnpike Road.
Miles.	Hours.	Pounds.	Tons.	Tons.	Tons.
2½	11½	83⅓	520	115	14
3	8	83⅓	243	92	12
3½	5 9/10	83⅓	153	82	10
4	4½	83⅓	102	72	9
5	2 9/10	83⅓	52	57	7·2
6	2	83⅓	30	48	6·0
7	1½	83⅓	19	41	5·1
8	1⅛	83⅓	12·8	36	4·5
9	9/10	83⅓	9·0	32	4·0
10	¾	83⅓	6·6	28·8	3·6

A horse which will haul 1½ tons of load on a macadamised road will haul 9 tons at 3 miles an hour on a narrow gauge railway.

A horse will carry a load of from 250 to 300 lb. on his back a distance of 20 miles a day on a common road.

The power of a pony or mule may be taken at from one-half to two-thirds that of a horse. The power of an ass is about one-fourth that of a horse. A pony or mule will pull half as much weight as a horse, and an ass one-fourth as much. These will carry a load equal to one-fourth their weight at a rate of 2½ miles in ten hours.

Man Power.—Man power figured largely in the works of the old writers on mechanics, Schulze, Desaguliers, Smeaton, Emerson, Coulomb, Regnier, Hachette, Buchanan and others. It is interesting to read of the numerous experiments that were made, for instance, on the relative power of tall men and short men, heavy men and light, the comparison of their work with that of horses, the employment of dynamometers, and the framing of algebraical formula on these subjects, and calculations in dynamical units.

The power of a man hauling on a level road is usually taken as equal to about one-sixth or one-seventh that of a horse. Both Smeaton and Desaguliers estimated it at one-fifth. It is reckoned at 2,200,000 foot pounds a day of ten hours, or 3,666 foot pounds per minute. Actually there are short intervals of rest in all working days, and hauling is a more economical method than turning a winch handle, or lifting vertically. In these circumstances it is not safe to reckon more than one-tenth of a horse power for the duty of a man. In working pumps, 1,000,000 foot pounds per day of ten hours can be accomplished by a strong labourer.

The following are different applications of human power. Turning a winch handle, 15 lb. pressure exerted at a velocity of 220 feet per minute. Drawing a boat, 12 lb. at 160 feet per minute. A labourer using a wheelbarrow and planks will take 20 cubic feet of earth a distance of 200 yards, and tip it, returning with the

empty barrow, in an hour. Using equilibrium trucks on a railway of 2 feet gauge, he will do the same work in one load in five minutes. Mr Bevan gave the following results of human energy employed for a short time, using:—

	Lb.
A draw knife, with a force of - -	100
An auger, with two hands - -	100
A screwdriver, with one hand - -	84
A common bench vice handle - -	72
A chisel and awl, vertical pressure -	72
A windlass, handle revolving - -	60
Pincers and pliers, compression -	60
A hand plane, horizontally - -	50
A hand saw - - - - - -	36
A stock-bit, revolving - - -	16

Experiments carried out at Barnum & Bailey's Circus, New York, gave the following results for the tractive effort of men and animals. They contradict the idea that the pull of an animal is limited to its own weight.

water is the method necessary. The subject, therefore, will be treated under various heads, leaving general considerations only for the present article. *See* **Aluminium, Brass, Chains, Iron, Malleable Cast Iron, Sheets, Steel, Steel Castings, Tube Drawing, Wire Drawing**, and other terms.

The effect of annealing is obvious and practical, the explanations are various, and sometimes obscure and unsatisfactory. The effect is to remove internal stresses, and the hardness which is produced in metals by the severe work done upon them, being that due to heating, casting, hammering, punching, rolling, drawing, and allied operations. The process applies to crystalline, and fibrous metals and alloys alike. Annealing usually lessens absolute strength, but imparts more ductility, lessens the risk of cracks, and of sudden fracture, but lowers the elastic limit. It is the only condition under which a good many operations are rendered possible, the most striking

PULLING STRENGTH OF MEN AND ANIMALS.

Number.	Description.	Weight of each in Pounds.	Total Pull in Pounds.	Pull per Unit.	Pull per Pound of Weight.
					Lb.
2	Horses	1,600	3,750	1,875	1·172
50	Men	150	8,750	175	1·166
100	Men	150	12,000	120	0·8
6	Horses	1,800	8,875	1,479	0·822
2	Camels	1,800	2,750	1,375	0·764
1	Elephant	12,000	8,750	8,750	0·739

Annealing.—The derivation of this word—Anglo-Saxon *Anælan*, from *Aelan*, to kindle, light, set on fire, or bake—only explains half the meaning of the term as now employed in workshop operations. The method of subsequent cooling is often of equal importance with the heating, and this depends on the material mainly, and then on the degree of heat, or stage at which the work is accomplished.

In some cases annealing is performed in vessels or furnaces which are kept closed until the work is done,—cooling down gradually; in others cooling is done in ashes, or in air; in others plunging in cold, or in lukewarm

cases being the rolling and drawing of sheets, tubes, rods, and wires.

Though the term annealing is applied in all cases of the softening of metals, yet the processes involved differ materially in different metals, as will be explained under the special headings just noted. In cast iron, carbon is the important element which is acted on and changed, or removed, but in wrought iron and in mild steel, which contain the merest trace of carbon, we can only conclude that the changes are due to rearrangements of the fibres, or of the molecules of the metal. In brass again, something of the same kind must

occur. The only things which appear to be above controversy are the resulting facts, and not the *modus operandi*.

We have said that the object of annealing is to impart ductility, toughness, softness to metals or alloys which have acquired properties of an opposite character in the process of working, and that in effecting this, the tensile strength, and elastic limit, or yield point are diminished, but the capacity for elongation is increased. Some practical lessons of this kind may be deduced from the following experiments.

In researches on the heat treatment of steel, by the late Sir W. C. Roberts-Austen, a number of experiments were made to ascertain the effects of annealing on steel at different temperatures, ranging from 1,148° Fahr. to 2,012° Fahr., the temperatures in each case being maintained for half an hour. The bars taken contained percentages of carbon ranging from 0·130 in the lowest, to 1·306 in the highest, while silicon, sulphur, phosphorus, manganese, and arsenic also occurred in variable quantities in each series of the eight different sets of bars experimented on. No single variety was annealed at one temperature only. The bars were slowly heated up to the temperature determined on for a given series of experiments, allowed to remain at that for half an hour, and then left to cool down in the muffle. The breaking strain, the elongation in a length of 2 inches, and the reduction of area at fracture were ascertained for each bar as received. The interesting feature of these experiments is that they endeavoured to connect the results obtained by annealing with the existence of the different grades in which steel occurs.

The experiments on bars annealed at 1,148° Fahr. indicated, that the elongation and reduction of area were greatly increased at this temperature, being roughly more than doubled. Heating a series of bars to 1,328° Fahr. increased the elongation and reduction of area, but with considerable reduction in the breaking strength.

Another set of experiments was made on bars heated to 1,472° Fahr., on which no comment seems necessary. The next, however, at 1,652° Fahr., is interesting from the fact that at this temperature (900° Cent.) the whole of the ferrite dissolves in the solid "mother liquor" to form a solid solution of carbon in iron (Ferrite or β iron is the name given to a pure iron, which separates out of a solid solution of carbon in γ iron). But though at this temperature of 900° Cent. nearly all the constituents of the bars dissolve completely in one another, they separate again in the subsequent cooling; their ultimate forms, however, depend mainly on the rate of cooling. In these experiments it was found that the strength of bars containing beyond 0·871 per cent. of carbon had been increased considerably in the cases of the 0·947, and the 1·306 carbon bars, to the extent of 11·16, and 5·4 tons greater than the same bars annealed at 1,472° Fahr. This fact emphasises the importance of annealing bars of the carbon content named, at a temperature at which the carbide becomes dissolved. But this increase in strength is obtained at the sacrifice of a great reduction in area, and in the amount of elongation; in the case of the 1·306 carbon bars, from 33·9 to 5·58 per cent. reduction in area, and from 20·0 to 5·5 per cent. elongation. This, therefore, is a warning beacon to the workman, because heating to so high a temperature produces effects just the opposite to those which are sought to be obtained by annealing.

The main interest of this series of experiments, however, centres in the fact that this temperature, or thereabouts (1,652° Fahr.) has long been considered a suitable one for reheating low carbon steels which have become brittle from various causes. Professor Arnold says that the process was invented so far back as 1820 by a Mr C. Wardlaw. But though often adopted, it is unsafe, and should never be practised when steels have to be subjected to severe stresses.

Heating to 2,012° Fahr. resulted in burnt steel being produced, the temperature being far beyond that at which any annealing is ever attempted.

A frequent practice in annealing operations is to prolong the period during which metals or alloys are subjected to the high temperature, the idea being that the saturation of the structure is favourable to a rearrangement of the

molecules, and it is held by practical men that a prolonged saturation at a medium heat is much more favourable to good and safe annealing than exposure for a shorter period to a higher temperature. Experiments performed for the Alloys Research Committee were made with a view to ascertain the effects of such "soaking" at different temperatures. It was found that there is a marked difference in the results of annealing the same bars for short, and long periods, confirming in this respect the experience of the shops. Prolonged "soaking" for twelve hours at the low temperature of 1,148° Fahr., by comparison with annealing the same series of bars at the same temperature for half an hour, resulted in most cases in a greatly increased elongation, and reduction of area, the increase being most pronounced in the high carbon specimens. Thus, taking four bars only, relatively high and low in carbon, the difference in the half hour and twelve hours' duration is shown below.

Experimenting at a temperature of 2,192° Fahr. showed in the case of high carbon bars a reduction in the breaking strain and elastic limit, with an increase in elongation and reduction of area.

The researches on these steels are to some extent vitiated by the fact that they were of a very unsatisfactory degree of purity. Besides which the test bars were of small dimensions, having an area of a quarter square inch; and 2 inches between gauge points. These dimensions were much below those generally adopted in commercial testing.

Mr Campion has stated as the result of his experiments that the best temperature for annealing large bars of from 4 to 6 inches in diameter with carbon contents up to 0·20 per cent., ranges from 1,292° Fahr. (700° Cent.) to 1,472° Fahr. (800° Cent.).

Turning to the work of the shops, annealing is employed in every department in which the working of metal is carried on. Many of these

	Carbon, per cent.	Breaking Strain, Tons per Square Inch.	Elastic Limit, Tons per Square Inch.	Elongation on 2 Inches, per cent.	Reduction of Area at Fracture, per cent.
Half Hour	0·180	30·60	26·50	33·00	62·85
	0·722	50·22	31·68	20·50	33·48
	0·871	55·02	29·28	12·0	22·11
	0·947	52·90	34·20	15·0	27·0
12 Hours	0·180	26·81	14·31	32·50	71·43
	0·722	40·63	21·13	29·50	46·54
	0·871	45·25	21·96	19·50	30·82
	0·947	45·41	23·15	18·50	27·10

This of course is accompanied by a reduction in breaking strength, and lowering of elastic limit.

Submitting specimens to the same prolonged treatment at a temperature of 1,328° Fahr. showed clearly that no advantage was to be gained by this rise of temperature, but rather the reverse. Another twelve-hour experiment at 1,652° Fahr. gave breaking strains nearly identical with those of bars annealed at the same temperature for half an hour; the elastic limit was much higher, but the elongation and reduction of area mostly less.

will be discussed in detail in their proper connections, but some observations thereon are called for here. Broadly we may consider the subject from the point of view of metals and alloys which either contain, or do not contain carbon.

First in regard to castings. Cast iron, cast steel, and malleable cast iron are subjected to this operation. In the first two cases the results must be regarded as physical only, in the third they are chemical. In the first two the result is accomplished by the removal of internal stresses, in the third by the elimination of

carbon. Annealing hard castings, whether in iron or steel, is the reverse of chilling. Leaving heavy castings covered in their moulds until quite cold exercises an annealing effect, and is so important in massive pieces that it is commonly practised. To take a heavy casting from the sand while red hot chills the exterior and sets up internal strains. Castings which have become curved are sometimes straightened by heating them, and annealing while loaded. Car wheels of cast iron are rendered safe by annealing them in boxes, by which process local strains are removed.

In neither of these cases, excepting that of malleable cast iron, can any change in the carbon be considered as being responsible for the results. Neither can such change be the cause in the annealing done in the boiler shop, in bent, and flanged work, nor in the work of the coppersmith, nor in the pressing and drawing of tubular cases, nor in work which is raised into various patterns by the hammer, nor in drawing tubes and wires. The removal of internal strains alone can be regarded as the explanation. In much of this work the annealing must be repeated many times during the progress of the work.

The subjects of **Cementation, Chilling, Hardening**, and **Tempering** are closely allied to that of annealing. They are all possible by reason of the molecular condition of metals, which comprise particles with open spaces, that permit of diffusions, and rearrangements taking place. *See also* **Alloys, Microstructure of Metals**.

Annealing Ovens or Furnaces.—There are special types of furnaces for some kinds of annealing, and for the treatment of large quantities of stuff, as in **Malleable Iron Castings, Milling Cutters**, tube drawing, and others; but there are probably as many furnaces which are built primarily for other work, and used for annealing as a matter of convenience. The most familiar examples are the reverberatory furnaces of the angle iron smith, and the boilermaker, and the core ovens of the moulder, both of which are largely improvised in the factory. Annealing furnaces are generally of the reverberatory type, being fired with solid fuel, or with gas. The maintenance of an equable and suitable temperature is essential, and in tempering cutting tools, dies, and small articles this must be fixed by means of a **Pyrometer**. Muffle furnaces are frequently used for annealing. In some annealing furnaces the articles lie exposed on the hearth, but in most they are hermetically sealed in pots, or in crucibles, or other vessels. Another difference is that the articles are often packed in contact with decarbonising agents, and luted down.

Annealing Pots.—Vessels in which many articles to be annealed are packed closely, before being put into the furnace. They vary in shape and dimensions, with different kinds of work. They will be found illustrated in connection with the work in which they are used. *See* references thereto in **Annealing Ovens or Furnaces**.

Annular Valve.—A valve which rests on a circular seating, and is thus distinguished from the hinged, or flap types.

Annular Wheels.—These may be either external or internal gears, since the term simply denotes the ring formation, in contrast with that of wheels having arms.

There are various reasons why annular gears are used. In the case of those with internal teeth, the reason is obvious. But many wheels having external teeth are made in the form of rings either from necessity, or for convenience, or with a view to economy. The largest rings are those used for swing bridges, block setting cranes, and other large cranes of revolving types, and these are all of necessity cast as separate segments of circles, and bolted down to their foundation girders. The cross section of such rings is that of two webs at right angles, one being the rim carrying the teeth, the other that of the flange through which the bolting down is done.

Some annular rings are made in segments, not because they are too large to be cast solidly, but because they can be removed if accidentally broken, or when worn, without dismantling an entire piece of mechanism to do so. This is the reason why many slewing rings are so fitted to revolving cranes around the post, and below the side frames.

Annular gears are often made solidly, and bolted to the faces of other work for convenience

of manufacture. Cases occur in the travelling wheels of overhead cranes. A better job can be secured than as though the two were moulded and cast together. In case of fracture of a tooth, or of wear, it is easier to renew the toothed ring alone than the running wheel also. Rings too are often used, because the teeth are cut, work which could not be done if the wheel were cast solidly with another piece.

A third reason why annular wheels are used is to employ a more durable and expensive material for the wheel teeth than is required for the wheel centre. The most familiar example of this kind is afforded by the present practice in high-class travelling cranes, and motor drives for machine tools, &c. The cast-iron centre receives a toothed ring of hard bronze, which is vastly more durable, and the thickness of which is made only sufficient to afford a good margin against the chance of spring, and distortion occurring.

Annunciator.—The annunciator is the apparatus that is employed in connection with electric bells and telephones, to show which room or which number has been called. With electric bells, the annunciator consists of an electro-magnet arranged to operate some form of trip action, releasing a shutter which drops in front of a numbered or named hole in the glass front of the annunciator case. In some cases the annunciator takes the form of a pendulum which swings in front of the hole when a call has been made. The shutter falls or the pendulum swings, when a current passes.

For telephone exchanges, the old form of annunciator consisted of an electro-magnet, against the holes of which a shutter was held, the shutter falling down when a current passed through the coils, and disclosing the number calling. In later exchanges, the annunciator consists of a very small incandescent lamp, which lights up when a call is made; a second, rather larger lamp, common to a certain number of subscribers, also lighting up, to show the superintendent that calls are being answered. The large lamp is extinguished when the operator answers the call.

Anode.—Anode is the term applied to the conductor by which an electric current enters either a liquid or a gas. It is the positive plate in any electrolytic process, and the positive terminal in any arrangement of vacuum or other tubes, through which it is designed to pass electric currents. It is the metal plate of an electro-deposition bath; the silver plate with a silver bath, the gold plate with a gilding bath, the copper plate with an electrotyping bath. It is the zinc plate of the galvanic battery, or the iron or other plate, in those rare cases where any metal is used other than zinc, for generating electricity. It is the metal plate, or metal electrode of any form, where the current enters the Crookes, or X ray tubes, and from which it passes to the cathode. As a rule the anode wastes in the processes for which it is used.

Anthracite.—This is the hardest variety of coal existing. It contains more carbon than any other, from 90 to 95 per cent.; its specific gravity is higher, and also its lustre, and its brittleness. It does not soil the hands. Its fracture is conchoidal, it ignites with difficulty, burns with a feeble flame, and gives out intense heat without smoke; the last being the property which renders it so essential in the boiler furnaces of warships. Anthracite exists in the largest quantities in Britain, in the South Wales coalfields. In Ireland it is found in Kilkenny, hence the term Kilkenny coal is sometimes given to anthracite. It occurs in Belgium and Westphalia. The largest American deposits are in the great Pennsylvanian coalfield.

Anthracite lies at the opposite extreme to bituminous, or flaming smoky coal, but there is a gradual transition from one to the other. The nearest to anthracite is culm, an impure anthracite, containing earthy matters, though the term is commonly applied to denote anthracite. Coals which more nearly resemble anthracite than the bituminous qualities are properly termed anthracitic coals. A Welsh anthracite has carbon, 91·7; hydrogen, 3·78; oxygen, 1·30; nitrogen, 1·0; sulphur, 0·72; ash, 1·5; sp. gr., 1·37. Pennsylvanian anthracite has 87·127 of carbon.

Dr Percy published a table showing the amounts of hydrogen and oxygen by comparison with carbon in various fuels, which is reproduced here.

	Carbon.	Hydrogen.	Oxygen.
Wood (mean of 26 analyses) - -	100	12·18	83·07
Peat - - - - - -	100	9·85	55·67
Lignite (average of 15 varieties) -	100	8·37	42·42
Ten Yard Coal, South Staffordshire -	100	6·12	21·23
Steam Coal, from the Tyne - -	100	5·91	18·32
Pentrefelin Coal of South Wales -	100	4·75	5·28
Anthracite of Pennsylvania (U.S.A.) -	100	2·84	1·74

Pure anthracite is difficult to ignite, or to burn in small fire grates. It therefore requires grates larger than those used for bituminous coal, and heavier charges. But the anthracitic coal, to which the Welsh steam coals belong, burns more freely. It decrepitates on the application of heat, as the pure anthracite does; and it is nearly smokeless. As it produces a higher temperature than bituminous coals, it burns out the grate bars more rapidly. Its evaporative power is less than that of bituminous coals. Anthracite so closely resembles pure coke in its large amount of carbon, and small proportion of volatile matters, that it is mostly used in American blast furnaces instead of coke, the latter being the fuel employed in Britain.

Anthracitic Coals.—*See* **Anthracite.**

Anti-Foaming Pipe.—*See* **Anti-Priming Pipe.**

Anti-Friction Alloys.—*See* **Bearing Metals.**

Anti-Friction Bearings.—*See* **Ball Bearings, Roller Bearings.**

Anti-Friction Compounds.—*See* **Lubricants.**

Anti-Friction Curve.—*See* **Schiele's Curve.**

Anti-Friction Metals.—*See* **Bearing Metals.**

Anti-Friction Rollers.—*See* **Roller Bearings.**

Anti-Incrustation. — *See* **Incrustation, Feed Waters.**

Antimony (symbol Sb, *Stibium;* comb. weight, 122; sp. gr., 6·71).—This metal is of interest to the engineer, because, though too brittle to be employed alone, it is of considerable value as an alloying element. The pure metal occurs in a native state, but the principal ore is the tri-sulphide Sb_2S_3. The grey antimony ore contains when pure 71¾ parts of antimony with 28¼ parts of sulphur. In appearance it resembles a bundle of dark grey metallic needles converging to a point. Its sp. gr. is 4·63. It is associated with galena, and iron pyrites, and with quartz, and heavy spar, from which it is reduced by mixing the ore with coal, and heating in a reverberatory furnace. The metallic antimony is extracted by heating the crude antimony with about half its weight of iron, when ferrous sulphide and metallic antimony result:—

$$Sb_2S_3 + Fe_3 = Sb_2 + 3FeS.$$

There are several stages in the extraction of the pure metal, which vary also with the richness of the ores.

The colour of metallic antimony is a bluish white. It is so brittle that it can be pounded in a mortar. A slight tap with a hammer will break an ingot. Its melting point is generally given as being 440° Cent., or 824° Fahr.; but Mr Stead states that this is not correct, and that he has found it to be 630° Cent., or 1,166° Fahr. M. Gautier has given it as 632° Cent., or 1169·6° Fahr. Though it does not oxidise at ordinary temperatures, it is rapidly oxidised if exposed to the air while in a molten state. If heated more strongly, it burns with a white flame, giving off fumes of antimony trioxide. Nitric acid converts antimony into antimony pentoxide, Sb_2O_5. Neither dilute hydrochloric nor sulphuric acids attack the metal. Antimony forms oxides, chlorides, and sulphides, and also unites with hydrogen to form a gaseous compound, SbH_3, analogous to AsH_3, which concern the chemist chiefly.

Antimony is one of that small group of metals which expand in cooling. Its value lies in its capacity for hardening the softer metals, as tin and lead, and in the brilliancy of the alloy which it forms when mixed with tin. Alloyed with lead it is employed for type metals. Britannia metal is composed of 3½ cwt. of block tin, 28 lb. of antimony, 8 lb. of copper, and 8 lb. of brass. Babbitt metal contains 3·7 parts copper, 7·4 parts antimony, and 88·9 parts tin. Various type metals are composed thus:—

Antimony.	Lead.	
1	3	For the smallest, hardest, and most brittle types.
1	4	For small, hard, brittle types.
1	5	For types of medium size.
1	6	For large types.
1	7	For the largest and softest types.

they become the most obvious feature, and when separated are found to consist of SbSn. The creamy layer which results from the alloying of antimony with lead is found on analysis to consist of nearly pure antimony, containing only 0·2 per cent. of lead, while the eutectic alloy which has a definite chemical composition of Pb_4Sb containing 12·7 per cent. of antimony, has a specific gravity of about 10·5. Additions of antimony increase this creamy mass. These are interesting facts which have a bearing on the work of casters in the soft alloys. The presence of isolated bright spots in these indicates an alloy which is not perfect. A perfect alloy is bright all over its surface. These spots occur wherever one part of an alloy crystallises after another part, and this happens when the proportion of either constituent is increased so much that a mass of crystals forms on the surface of the eutectic alloy, which being more

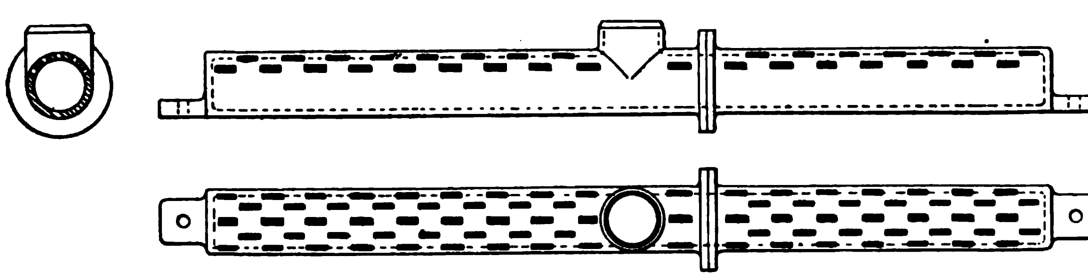

Fig. 101.—Anti-Priming Pipe.

Stereotype plates contain from about 4 to 8 parts of lead to 1 of antimony.

The researches of Mr Stead have emphasised the fact that alloys of antimony must be cast at as low a temperature as possible (resembling in this respect those in which aluminium predominates). He found that though the specific gravity of antimony is 6·71, that of its eutectic alloy with lead is about 10·5, the result being that the moment the cubes of antimony crystallised in the cooling mass they floated up to form a creamy layer on the top. But casting cool, and in cold moulds, does not afford time for the separation to take place. In working with tin and antimony similar results follow. Under ordinary conditions of casting—adding 10 per cent. of antimony to the tin—the surface becomes covered with little cubes of a hard bright substance, which increase until at 30 per cent. fusible, shrinks down, leaving the crystals of the higher melting compound in relief. The markings on solders that are improperly mixed are due to this fact.

Anti-Priming Pipe, or Anti-Foaming Pipe.—The pipe which is carried along within a steam boiler for the purpose of collecting steam free from an excess of suspended particles of water. It is commonly used in place of the steam dome. Such a pipe is shown in Fig. 101, as made for a Lancashire boiler. It is of cast iron, having a number of perforations of slot form, along its upper surfaces, through which steam is admitted. The lower area of the pipe being solid, throws back most of the spray which is ballooned upwards by the ebullition going on, leaving the steam to pass upwards out into the supply pipe. The slot holes usually measure about ½ inch wide, by from 2 to 2½

inches long. Their total area must be in excess of the bore of the stop valve. For a standard Lancashire boiler the bore of the pipe is usually 6 inches. The pipe is supported freely, close to the boiler crown where the steam is driest, being carried by a couple of bolts attached to lugs at the end of the pipe, and themselves being pivoted in small angle pieces riveted to the shell.

Anvil.—The mass of metal which provides the reaction to the blows of hammers. The name is derived from the Anglo-Saxon *Anfilt*, or *Aenfilt* (*andvile* in Spenser). Strictly, that on which things are built or fashioned.

Anvils include those used by smiths, variously engaged in engine and machine forgings, for angle work, for coach work, by farriers, copper, and tinsmiths, and the anvils of power hammers; as drop, steam, pneumatic, and hydraulic. Some and swages. It is of value in fixing some of the smaller bending blocks and stamps used at the forge, and for inserting small bars to commence a bend. The anvil is always carried on an **Anvil Stand**.

Transition forms between the smith's anvil and the coppersmith's and tinmen's stakes are the portable bick irons, and the anvil stakes, one of which is drawn at Fig. 105, C. These resemble one another in the possession of tapered shanks which fit into blocks of wood or metal, and their working faces are flat, and variously concave. The stakes proper, though true anvils, are so differently shaped, and their functions are so numerous, that they are treated as a separate group under the term by which they are known in the coppersmith's and tinmen's trades. *See* **Stakes**.

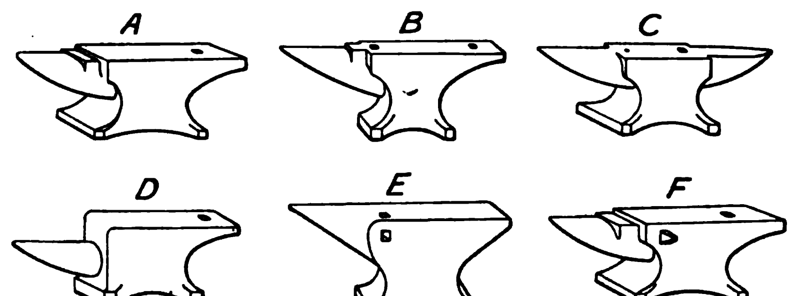

Fig. 102.—Group of Anvils.

A. **Smith's anvil.** *B.* **Ditto, Soho pattern.** *C.* **Double bick.** *D.* **Boilermaker's.** *E.* **French shape.** *F.* **Coachsmith's.**

typical illustrations of smith's anvils are given (Fig. 102).

In the smith's anvil, various differences occur in shape and size. The principal is that due to having one beak or bick, or two. In general the smith's anvil has but one, the cross section of which is circular, being used for bending over, and turning eyes round. When there is a second at the opposite end of the body it is of rectangular section, on the upper portion at least, so that angular bendings can be done, but this form is unusual. Generally the bick is set down a little below the angle face, but in what are termed French and Italian shapes it is flush. An anvil has one hole, frequently two, to receive the anvil cutter, or anvil chisel. It is also used to set bottom tools in, as the fullers,

The largest anvils are those used for power hammers. The term is applied sometimes to the mere block on which the forging is manipulated, but sometimes to the entire mass of metal which is carried on the foundation below the ground. This is more frequently termed the **Anvil Block**.

Anvils are differently made. Those for steam hammers are of cast iron. The smith's anvils are made of wrought iron, faced with steel welded on. In America large numbers of cast-iron anvils, steel faced, are used. Wrought-iron anvils employed there are mostly imported from England or Germany. A well-made wrought-iron anvil, free from flaws, has the "ring" which is so familiar in the smithy. The method of manufacture of these anvils is as follows:—

The core or body is made in one piece, in the best anvils, to which the horns which fit into the anvil stand are welded on, as is also the beak, or bick, each by butt, or jump joints. The quality of this body iron is not of the best, as it has no work to endure beyond the concussive force of the blows dealt on the anvil. The working face is of steel, usually shear steel, in preference to cast steel, as being easier to weld. The body and the face being brought to a welding heat, the welding is done by sledges wielded by four strikers, a few inches at a time, beginning at one end, and taking fresh heats successively until the entire length is closed. The anvil is finished to neat outlines in subsequent heats. The steel face is ground, and then hardened. The latter work is done by bringing the upper face to a red heat, and letting a stream of water fall upon it from a height of about 10 feet.

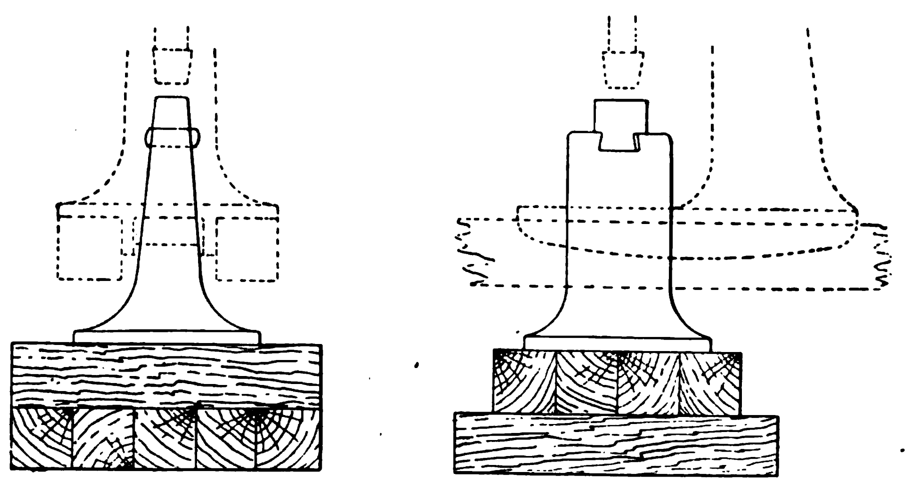

Fig. 103.—Anvil Block for Small and Medium-sized Hammers, on Wood Blocking.

The anvils made in America, of cast iron, are of a high grade of metal, which is necessary to stand the concussions of hammer blows, and the cast steel faces and bicks are welded on. The welding is done at the time of casting, the steel face being heated to a bright colour, and laid in the bottom part of the mould, over which the iron is poured. After removal from the mould, the anvil is annealed, trimmed, planed, and finally hardened. If the welding is not perfect, the hardening will find out the bad place and crack the anvil. There is less ring in these anvils than in those of wrought iron.

In a micrometer gauge the fixed abutting piece against which one end of the article to be measured is set, is termed the anvil. *See* **Micrometer Caliper** for illustrations.

Anvil Block.—The mass of metal which carries the anvil, or the bottom dies of a power hammer, and which, by its mass, absorbs the shock of the blows. The separation of the anvil from its block is a matter of convenience, because any number of anvils, small, or large, and forging dies can be secured to the top of the block by a dovetailed tongue, or by set screws. Moreover, all wear or damage that takes place occurs on the anvil or dies, which can be easily replaced with new, while the anvil block is never, apart from accident, renewed.

The anvil block tapers upwards, Fig. 103, as being the shape most suitable to resist concussions tending to flake off pieces in diagonal directions, an accident which does occasionally occur. The greater portion is buried beneath the floor level, and its base rests on broad **Anvil Foundations.** The horizontal cross section of the block is generally rectangular, but the base is always so shaped, the reason why this is preferred to a circular form being that the block cannot then shift round in course of time under the jar of hammer blows. This confinement is essential

in order to keep the dovetailed grooves that receive the anvils or dies always in the axis of the hammer above. The area of the base is large to avoid chance of settlement.

In a few cases the anvil block and the bed-plate which carries the upright framings of the hammer are cast in one piece. This is not a good plan, because the uprights then receive all the shocks due to the hammer blows, with injurious results. The method is never adopted in large hammers, and is not suitable for small ones, but the anvil block and the bed-plate for the hammer framings should be kept entirely distinct.

The weight of an anvil block varies as a minimum from about 6 to 1 of that of the weight of the hammer, in single-acting hammers, to 12 to 1, or more, in double-acting ones, though a long time to cool, from several days in the smaller sizes, to some weeks in the largest. If they are stripped of the sand too soon, the metal in the interior will remain hot, while the exterior cools too rapidly, and "draws" will occur, which in some cases have resulted in fracture of the block.

The blocks are cast with the base uppermost, Fig. 104, in order to get the soundest metal on the working face. The trunnions are cast on a little above the centre of gravity in order to permit of the easy turning over of the blocks. Holes are frequently cast in blocks for the insertion of bars to be used in making adjustments when setting them.

When very massive blocks are cast in place, they are still poured upside down and turned

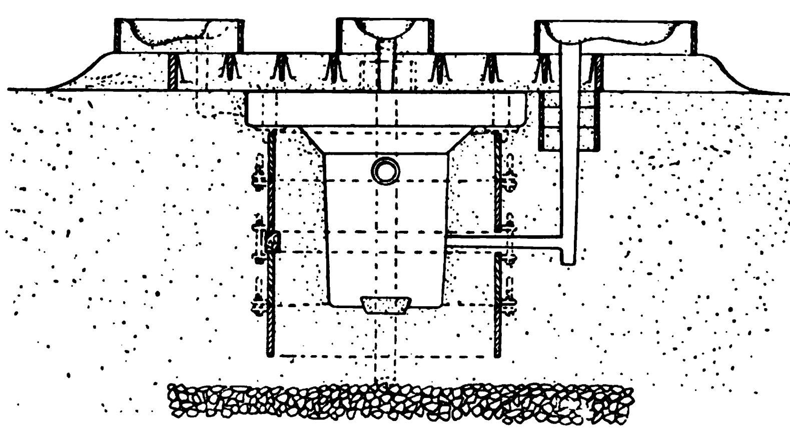

Fig. 104.—Vertical Section through Foundry Mould of Anvil Block of Medium Dimensions.

these ratios are not by any means of an exact character. Thus a block for a 12-ton hammer at the Dalziel Steel Works weighs 170 tons. But one at the Osnabrück Works in Germany, also for a 12-ton hammer, weighs 250 tons.

This great weight is a source of difficulty in casting, the blocks for the smaller hammers used in ordinary engineers' smithies excepted. It is not that the pouring is difficult, but the subsequent removal and transportation from the foundry to its location, and the placing it in position. There are therefore two methods adopted, either to cast the block in separate pieces (*see* Fig. 108), or to pour it *in situ*. If cast in pieces, the parts must be well bonded together, but a solid block is preferable. Large blocks take over; and cupolas are erected close to the spot. The anvil block of the Perm hammer, weighing 623 tons, was cast in place. One weighing 1,000 tons was so cast at the Terni Steel Works in Italy. The anvil block at Perm, cast upside down, was turned over on its trunnions by two steam engines, in two hours and a half. The metal was melted in fourteen Mackenzie cupolas erected round the mould, supplied with blast by three blowing engines. 1,724,000 lb. of iron were melted, with 136,480 lb. of anthracite coal, and 106,570 lb. of coke, and the cost worked out to £15. 16s. 11d. per ton.

Anvil Chisel, or **Anvil Cutter**.—A short stout cutter with a straight chisel edge, doubly bevelled, which is dropped by a stem or shank

into the square hole in an anvil face, Fig. 105, A. Rods, bars, forgings, are laid upon this and nicked hot, or cold by striking them with a hammer over the cutter, and turning the rod or bar round, unless of small dimensions, between blows. Actual severance need not be done, because a bar nicked round can be easily fractured.

Anvil Cutter.—*See* **Anvil Chisel.**

Anvil Foundations.—These are a most important and costly portion of the equipment of steam hammers. Not only must the **Anvil Block** be massive, but it must be properly supported on sound foundations, to avoid risk of settlement sideways. The nature of the immediate support given to it is generally wood, but this must be supported on a good base, which is either concrete or masonry, or timber piles, the last being suitable in shifting and loose soil. The reason for this is that the force of the blows, and the mass of the anvil block require a broad and deep base to receive the stresses, without risk of displacement being caused. The great value of timber, which leads to its use in the majority of cases, lies in its elasticity, by virtue of which the vibrations and concussions are absorbed and dissipated in and around the foundations, instead of being allowed to react injuriously on the hammer framings and mechanism.

Some typical foundations are shown in Figs. 106-108, in all of which timber is used. Oak is the best material, bolted together, frequently in two depths, with the pieces crossing at right angles. In making such foundations, a hole is excavated until solid ground is reached, either stiff clay, or gravel, or rock, and a good depth of concrete, from 3 to 6 feet, according to circumstances, is laid down on this, and levelled. This receives the timbers which support the anvil block, or an intermediate body of timber of large area, or in some cases a layer of intermediate masonry. When the anvil block is laid in place it is wholly enclosed, excepting for the 10 or 12 inches or so that appear above the ground, by concrete or by rubble, in various ways. This is frequently confined between walls of masonry built up from the concrete bed. Examples of these are given in the illustrations.

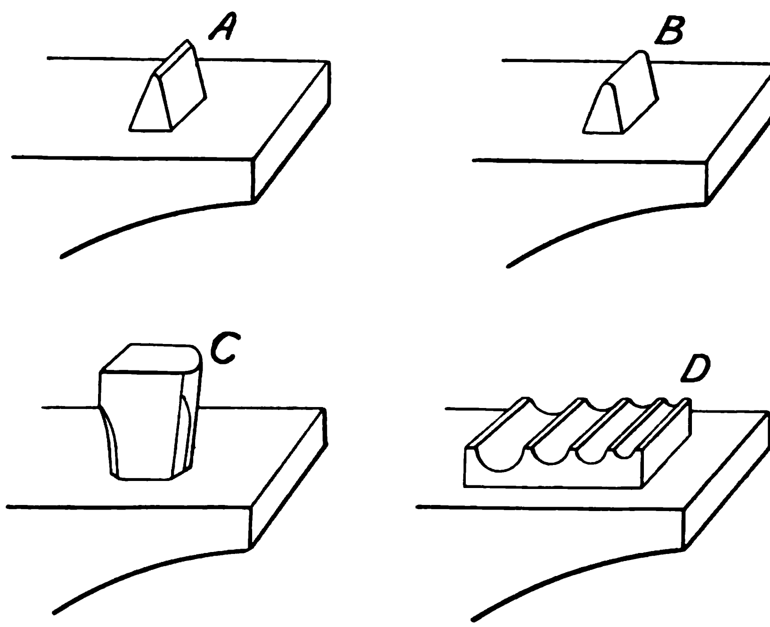

Fig. 105.—Anvil Tools.
A. Anvil cutter, or chisel. *B.* Anvil fuller. *C.* Anvil stake. *D.* Anvil swage.

Anvil Fuller.—A fullering tool which is set by a tang or shank in the square hole in the

anvil face (*see* Fig. 105, B). Work is reduced in stages between this and a top fuller held by a handle of wood.

Anvil Stake.—*See* **Anvil.**

Anvil Stand.—All smiths' anvils have to be raised up from 10 inches to a foot above the

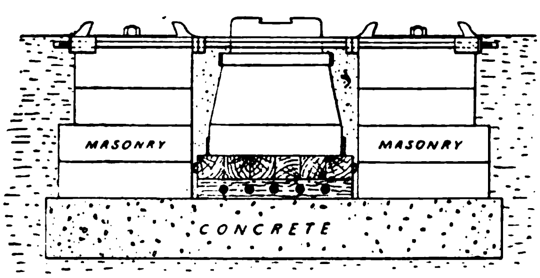

Fig. 106.—Anvil Block carried on Crossing Timbers, supported on Concrete. Frames supported on Masonry.

ground on a stand. Many of the stands used by country smiths are formed of a piece cut from the trunk of a tree, and set end grain upwards, or of a length cut from a large balk of timber. But generally in factories a cast-iron stand is

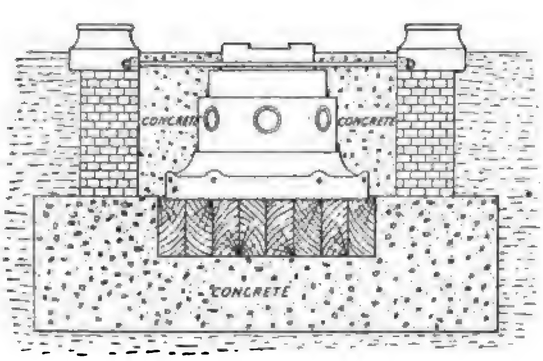

Fig. 107.—Anvil Block in Concrete, confined in Masonry.

used, Fig. 109, having a shallow recess into which the feet or horns of the anvil drop, and within which they are confined. It is not then necessary to secure the anvil to the stand with any fastening. But where a wood block is used, the mass of which is not equal to that of iron, straps or bolts have to be employed for this purpose.

Anvil Swage.—A bottom swage which fits by a square tang in the hole in an anvil face. It generally contains from three to four cavities of different sizes, to save changing swages when drawing down at one heat (*see* Fig. 105, D).

Apex.—The summit or peak of a conical or pyramidal figure. Signifies the points of the angles which compose the lattices of Warren and similar girders, that are attached to the top and bottom booms.

Aplanatic Lens. — The nomenclature of photographic lenses is in a somewhat chaotic state. As each maker has introduced a fresh

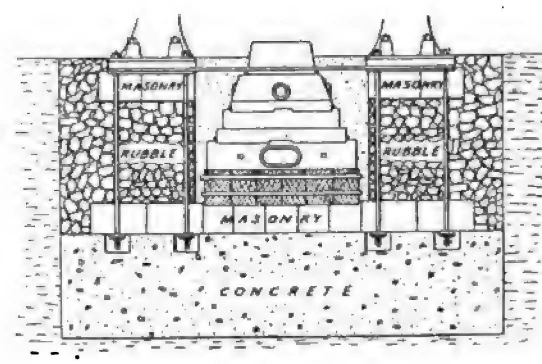

Fig. 108.—Anvil Block cast in Sections, supported on Timber, Masonry, and Concrete.

type or a development of an existing type of lens he has coined a new word, so that the derivation of the word from its foreign roots often fails to give a clear idea of the qualities and powers of a lens. The Aplanatic lens is really a type of the Rectilinear lens, consisting of two similar combinations with their concave surfaces facing each other, the diaphragm being placed between these two combinations. The

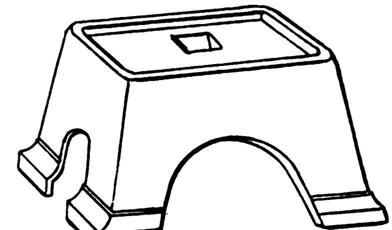

Fig. 109.—Anvil Stand.

name Aplanat is generally confined to Rectilinear lenses possessing a full aperture ranging between F7 and F8. For the photography of machinery the Aplanatic is a good lens, its chief defect being

the lack of marginal definition at full aperture. Except, however, where workmen pose with a machine, speed is of no consideration, and the lens may be stopped down considerably so as to give even definition all over the plate. Like other Rectilinear lenses, they are generally symmetrical, that is the two doublets composing the entire lens may be used separately and have a focus double that of the complete lens. This quality is naturally useful, for the engineer's photographer generally has to adapt his apparatus to fixed conditions, the object being frequently immovable and the range limited.

Apparent Slip.—*See* **Screw Propeller.**

Apple-Tree (*pyrus malus*; sp. gr., 0·73; weight of a cubic foot, 45 lb.).—A hard, durable, close-grained wood of reddish-brown colour. It is used a great deal for the cogs of mortise wheels. It does not attain very large dimensions, and so is limited chiefly to the making of small articles. Apple-tree is a very nice wood to turn in the lathe. A smooth surface and fine polish can easily be produced on it.

Appliances.—This term is a very elastic and comprehensive one. It properly denotes something which is employed in aiding the work of the shops, but which is neither a motor, nor a tool, nor a machine tool, nor fixed plant. It does not shape, mould, or fashion materials, but it assists the action of the tools, and machines. It may take the form of an adjunct or aid to either of these; as a vice, a templet, a drilling jig, a bench, a trestle, or a hundred other shapes. But in each case it is an article which is not the primary instrument, or machine employed in the performance of mechanical operations. It may also be a desirable adjunct only, or it may be absolutely essential. But it does not cut, or shape, or impress, or produce in any way the actual outlines on the work.

In a loose way, the term "shop tools" is given to many appliances, such as bending blocks, jigs, foundry plates, and rings, boring steadies, and much else, but shop appliances is a more correct phrase than tools. This, however, is a minor question of words, since no confusion ever arises in consequence of the loose usage of the term. What we are concerned with here is the importance of appliances in modern shop practice.

The extended use of appliances is a fact which contrasts strongly with the older methods. There have always been some of these made, even in the earlier and unprogressive shops. But generally the management and the hands regarded them with little favour, the managers often thinking them expensive luxuries, and the men disliked them as being labour lessening. Another reason was that the possession of some experience and aptitude is generally necessary to the successful scheming of such aids to the tools and machines. In most shops now this is relegated to men who are specialists, or to a department of the office.

Appliances are used more extensively in some departments than in others. They are least employed in the pattern shop, most in the machine shop, and in those smithies where stamping largely predominates. The term appliances covers many objects with diverse functions. They will be found described under numerous headings. Specifically reference may be made to **Dies, Jigs, Shop Tools, Templets.**

Appolt Oven.—*See* **Coke Ovens.**

Apprenticeship.—Unless otherwise qualified, this is understood to signify that system in which a lad is bound by an indenture for a certain term of years, usually seven, to learn the practice of a single trade. This is a different thing from the binding of an **Articled Pupil** to learn the profession of engineering as a whole.

At the present time, and indeed for several years past, ideas and customs respecting apprenticeship have been undergoing a change. It has long been felt that the institution is not sufficiently elastic, that it does not fully meet the requirements of modern industry, that it is neither fair to the lads, nor advantageous to employers. It has, for these and other reasons, to be presently noted, fallen largely into disuse.

The engineering, and allied occupations and trades in which a training extending over several years is required are:—Drawing, patternmaking, carpentry, moulding, smithing, boilermaking, plating, coppersmiths' work, metalturning, the operation of machine tools, fitting and erecting. In each of these, with the exception of machine tools, apprenticeship was

formerly the rule. In all of them now the governing custom is either to shorten the period of apprenticeship, or to abandon it entirely. This, however, does not mean that lads are not trained in the trades, but that the binding indenture is omitted. Many firms now will have nothing to do with indentured lads, because they are apt to become unruly, thinking themselves secure behind the bond. Lads are allowed to come into training as before, but they are liable to instant dismissal, like the men, if they prove unmanageable or incompetent. It is not to the firm's interest to discharge them, if they prove apt and industrious, neither is it to the lads' interest to leave until the craft is acquired. And so, on the tacit and honourable under standing only, that a capable lad shall be retained in the firm's service for three, five, or seven years, and that the lad himself shall remain there for some such fixed period, the system works, and has worked very well, without the formal and binding indenture.

The question of wages is affected by this custom. While standard rates of wages, advancing year by year, are generally fixed, it is found to mutual advantage that these shall not be of a hard-and-fast character. By means of piece-work, or bonuses, or by special advances made on the judgment of foremen and managers, capable lads receive encouragement and inducements to effort, and to remain with the firm.

In some departments there is greater disinclination to apprenticeship than in others. Apprenticeship, or its equivalent, is still retained in patternmaking, boiler-making, plating, metal-turning, fitting and erecting. But it is adopted less and less in moulding, and smithing, while it never has been much in vogue in the machine shop, and is now practically dead there. The reason for these differences is that handicraft still largely predominates in the trades where apprenticeship still exists, or where special skill in the handling of appliances is desirable. The trades where it is falling into disuse are those which have been largely invaded by machine methods. It is a fact that in some shops, very few trained smiths, or hand moulders, are employed. Though these shops as yet are rather exceptional, they indicate the trend of the present, and supply sufficient explanation why those who know these trades hesitate about apprenticing lads to them.

Nearly as long as the writer remembers, this movement, antagonistic to apprenticeship, has been going on. Many years ago the practice was growing of bringing some lads into some departments without apprenticeship. In the drawing office, lads begin as tracers; in the foundry as core boys; in the smithy as handy lads, helpers, holders-up; in the machine shop as minders of stud and bolt lathes, or of drills, shapers, or slotters, &c., under the charge of an old hand or chargeman. And what was happening then has been going on at accelerated rates since.

We may now consider the wide question of apprenticeship in the light of present-day developments.

Much misconception exists with regard to the utility of apprenticeship, and its effect in reducing the large proportion which unskilled, bears to skilled labour. Many social reformers advocate a general revival of this system as a panacea for the glut of unskilled labour, from which the ranks of the unemployed are recruited. But those who are familiar with the modern operations of industries are not able to coincide in that view in its entirety.

The great, unquestionable fact is, that the growth of machinery has largely displaced, and is displacing at an accelerated rate the skilled men which apprenticeship produced. The craftsman has gone, or is rapidly going in many trades, giving place to the mere machine hand, or lower still, to the machine minder. The engineering trades have suffered less than many other industries in this respect. But even here we see that better castings are often made by machines tended by men who are not moulders than the moulders working by hand can produce. In the smithy we see trained smiths replaced by stampers. In the machine shop, intelligence is required for handling the costly machines, because of the necessity for careful fixing of the work upon them, and making suitable adjustments for feeds and speeds, &c. The same holds good in the general turnery. But we find here that unskilled attention is invading the province of the craftsman. It is seen in the automatic screw machines, in the

automatic gear cutters, in the plainer class of grinders, and in the gauging of finished work. In proportion as these departments grow, is the demand for skilled labour lessened, and they are growing rapidly.

Outside the engineering trades, we see that skilled craftsmen have been displaced almost entirely by unskilled youths, and girls. It has occurred in nearly all trades in which mechanical operations predominate. It is notably the case in watchmaking, in boot and shoe making, in box-making, in envelope-making, and many others. To talk of apprenticeship in such trades indicates an entire want of knowledge or appreciation of the mechanical conditions under which those trades are prosecuted.

The fact is, apprenticeship, like the trade guilds, is an institution which was suited to conditions that have either passed, or are passing away, and it is as idle a task to attempt to revive it in such cases as it would be to try to revive the old guilds in the changed industrial life, or the old knights, in face of modern armies, or the picturesque but filthy mediæval cities and castles in face of the cleaner ideals of to-day.

Nor does this state the whole case. In those trades where handicraft is still in demand, the scope of the operations of the individual workman has been narrowed greatly. The days of the "all round" engineer, or carpenter, or joiner, or cabinetmaker, or bookbinder, or smith are nearly gone, are absolutely so in the large factories. In every craft the skilled men have been compelled by force of circumstances, over which they have no control, to become specialists. So that while large portions of the work which were formerly done by craftsmen have been appropriated by machines, the remainder is divided up among different men, or groups of men, who would in most cases be indifferently qualified to turn their hands to any of the other specialities of the craft, with results profitable to themselves or their employers.

These facts, which are stated in barest possible outline, being obvious to those who are familiar with industrial operations, explain the growing disuse of apprenticeship. It is not that workmen object to the system; on the contrary they desire it, and would welcome its general revival. But it could be only a forced, unnatural growth, since it belongs to a class of industrial conditions that are of the past. To create anew an army of skilled craftsmen for whom there could be, under present-day conditions, but a limited demand, would bring disaster. The training of years is not wanted when the training of a few weeks suffices to make of a raw hand an intelligent and trustworthy machine minder, or tender.

There is, however, another aspect of apprenticeship, which is of recent growth, and that is being adopted in several large and leading works at home and abroad. It is an attempt to give a broader training than the old system affords, and to combine with it the advantages of technical education. It provides opportunities for apprentices similar to, but more restricted than those which are enjoyed by **Articled Pupils**, who have to pay heavy premiums. Permission is given to acquire knowledge in more than one department of a factory, the time spent in each being much shorter than that occupied therein by the ordinary apprentice or learner. And the time divided thus, between, say, two or three departments, alternates with time spent in the technical schools, so making a "sandwich" system of training, which is without doubt the best possible from the practical point of view.

The subject of apprenticeship may thus be regarded from a wider point of view than that which was ever contemplated under the old regime, and thus be made a corrective to the intensely narrowing influences of the daily life of the machine minder. No man is so helpless as the machine minder when his particular occupation is gone. He has learned to do but one thing well, subject to the iron rules and regulations of the huge factory machine, in which he is a mere mechanical unit. This is in truth the most serious and saddening labour problem, how to raise the labourers above the depressing influences of their daily tasks. Joy in one's labour is impossible when those tasks lie in watching and tending an automatic machine, performing only one set of operations from January to December. The all-round craftsmen manifest an interest in their duties,

and are proud to do good work, but the modern hand who tends a machine that produces thousands of similar pieces to "gauge," cannot feel pleasure and pride in the production of pieces the responsibility for which is transferred from himself to the tools set up in the machine.

The only thing that will counteract this depressing condition is, paradoxical as it may seem, a broader training. That may not bring increased income, though it will give the capable man better chances of success. But a man will be better for understanding a great deal of the work of other departments than his own. And here the schools of handicraft come in. If a man wants a hobby he may always find that in the practice of some trade other than his own. The great technical institutions supply training in nearly all trades. In a modern factory no man or boy can observe the operations which are carried on in any departments other than his own. Each is a separate world, the bounds of which cannot be overstepped. If a lad desires to know what goes on outside his shop, he can only learn that in the technical trade classes. In this way many an ambitious lad can gain a good insight into the crafts that go to make up the practice of engineering, or other great industries, and so fit himself for a wider sphere of usefulness. And if success, measured in money, should never come to him, he will be a better man for his wider knowledge, and be lifted thereby into a sphere of broader intelligence, and better appreciation of what is involved in the work towards which he contributes his tiny quota.

Apron.—The plate of metal in front of a slide rest between which and the bed, the clasp nut, gears, and feed arrangements are enclosed.

Aqueduct (Lat. *Aquæ ductus* = conducting of water).—The aqueduct of masonry is a bridge of arches, in the construction of which the Romans excelled, two examples of which are illustrated by Figs. 110 and 111 on Plate VII. The aqueducts of modern times have been built for the purpose of carrying canals, and for irrigation, but the most important works of this kind are those for supplying cities with water, as in Roman times, though the designs differ greatly from those of ancient periods.

Of the aqueducts that were built by the Romans for the conveyance of water to the capital city, the earliest was by Appius Claudius (about 50 B.C.), of which nothing remains. Fourteen in all are mentioned, three of which are still in use. The Aqua Claudia is supported on arches for 7 miles of its length, and it comprises upper and lower channels. Aqueducts were built in various parts of the vast Empire, at Antioch, at Mitylene, at Pyrgos, Metz, the Pont du Gard, near Nismes, Segovia, and Spoleto.

The first aqueduct built in this country was Barton Bridge, by Brindley (1760), on the Bridgwater Canal. The idea of carrying water over a bridge was deemed preposterous at that time. The first aqueduct in which cast-iron plates were used in place of puddle for the bottom was the Chirk, built by Telford. The second was that at Llangollen, over the Dee, which has cast-iron plates bolted to form a trough, and supported on cast-iron ribs. This aqueduct has nineteen arches, making a length of 1,007 feet, and it was also Telford's work.

Aqueducts used for modern waterworks are of a different character from those of antiquity. Instead of building expensive masonry, at a nearly uniform level, advantage is taken of the fact that water finds its level, to carry pipes and culverts down through valleys, leaving the more costly arched or girder bridges for the support of pipes or open channels over streams or railways. And here the cast-iron arch is often retained, since the load is quiescent, differing from that of the passage of railway trains, or heavy road traffic. Some of the great waterworks of this country supply illustrations of aqueducts carried over distances of many miles.

The following are the lengths of the principal aqueducts in Britain :—

	Miles.	Areas Drained (Acres).
Manchester-Thirlmere -	96	11,000
Birmingham-Welsh - -	$73\frac{1}{3}$	44,000
Liverpool-Vyrnwy - -	68	23,200
Stockton and Middlesbrough	35	
Glasgow-Loch Katrine -	$23\frac{1}{2}$	26,295

The Manchester-Thirlmere aqueduct, to be precise, has a length of 95 miles 1,443 yards. It was commenced in January 1886, and completed in 1893. Thirlmere Lake is in Cumber-

Fig. 110.—Roman Aqueduct at Segovia. 2,400 feet long.

Fig. 111.—Pont du Gard, Nismes. About 180 feet high, sixteen centuries old. Three rows of arches, the upper row 873 feet long.

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land, about 5 miles south of Keswick. The aqueduct thence to Manchester comprises $14\frac{1}{2}$ miles of tunnels, cut-and-cover, 36 miles; and cast-iron piping 45 miles, weighing about 55,000 tons. The tunnels and cut-and-cover have a capacity equal to the full supply of 50,000,000 gallons per day, but five lines of pipes are necessary to convey this quantity, a single line affording a 10,000,000 gallon supply. The inclination in the tunnels and cut-and-cover is 20 inches to the mile, and in the pipes generally 24 inches to the mile.

The tunnels are 8 feet 6 inches wide where

valleys, where the pressure is equal to as much as 400, and 425 feet head. Fig. 113, Plate VIII., illustrates the laying of the last line of pipes in Scardale Valley.

At all places where the channel changes from one kind to another, as tunnel, or cut-and-cover to piping, and back again, a well is sunk containing valves for the automatic prevention of the forward flow of the water if a fracture should occur in the syphon on the lower or discharging side of the well. These automatic valves are very remarkable structures. They occur at the heads of each line of syphon, that

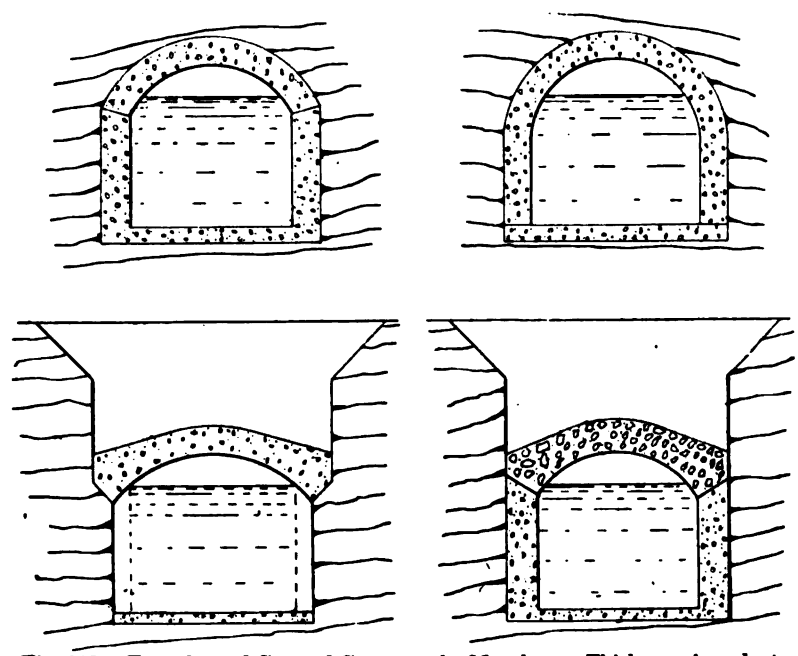

Fig. 112.—Tunnels, and Cut-and-Cover on the Manchester-Thirlmere Aqueduct.

there is no necessity for side walls and arching, and 7 feet 1 inch where lined with concrete or brickwork. The cut-and-cover is formed of concrete, and has the same internal section as the lined portion of the tunnels. The floors in all cases are concreted, either from necessity, or to give the water an easy flow. Fig. 112 shows typical sections of tunnels and cut-and-cover.

The pipe line is formed mostly of 48-inch pipes, 12 feet long, united with socket and spigot joints, run with lead, without yarn, and caulked. The thicknesses differ according to the pressure in different localities, being from 1 in. to $1\frac{3}{4}$ inches. The latter occur in the deep

is where the pipe lines go down from, or come up to the tops of the valleys in which they are laid. But besides these, there are other self-acting valves placed in the descending and ascending portions. Those on the latter are of reflux type, to prevent, in case of a cessation of the flow of water, the return of that which has passed the valve. Numerous stop valves, operated by hand, are also fitted and enclosed in valve houses. Air valves are fitted at intervals in the pipe line, on the highest summits, and these are enclosed in inspection boxes. Overflow chambers are also fitted.

In the Manchester-Thirlmere supply no less

than twenty-three bridges carry the aqueduct over rivers and railways. There are also ten subways that carry the pipes under railways. Bridges span the Ribble, the Lune, the Mint, the Sprint, the Brock, the Yarrow, the Darwen, the Calder, and others. The aqueduct is carried over the Ribble on an arch bridge of three spans of 70 feet each, built of cast-iron segmental arches. That over the Lune is similar, but it is a skew bridge. In both cases the segmental ribs are tied together transversely by six girders, each alternate one of which is of cast iron, the others of wrought iron.

The Birmingham-Welsh aqueduct, opened in 1904, is second only in length to the Manchester-Thirlmere one, being $73\frac{1}{3}$ miles long. Of this the various tunnels extend to $13\frac{1}{3}$ miles, the cut-and-cover to 23 miles, and the pipes to 37 miles. The longest tunnel is the Dolan, of $4\frac{1}{4}$ miles, which was driven from four headings, two from the ends, and two from shafts. The Knighton tunnel, $2\frac{1}{2}$ miles long, was driven from the ends only. Over Deepwood Dingle the aqueduct is carried in brick on a masonry bridge 500 feet long, with an area large enough to convey the full ultimate supply of 75,000,000 gallons per day. The pipes are ·42 inches diameter, some being of steel where the pressure is greatest (240 lb. to the square inch), others of cast iron. Each line of pipes will convey $12\frac{1}{2}$ million gallons per day. These pipes are carried over a steel arched bridge 3 miles from Bewdley, having a span of 150 feet.

Among modern works one of the largest aqueducts carries the Lower Ganges Canal over the Kali Naddi as an extension of the irrigation scheme of the Canal, and replacing an older one which was destroyed by a flood. In the Table at the bottom of page, the Nadrai Aqueduct is compared with another, the Solani on the Upper Ganges Canal, built in 1852.

The construction of the Nadrai Aqueduct swallowed up the following quantities:—

Earthwork - -	3,700,000 cubic yards
Puddle - -	130,000 "
Concrete - -	40,000 "
Brickwork - -	176,000 "
Pitching - -	9,260 "
Woodwork - -	100,000 cubic feet.

One of the most remarkable features of this great work was that three-fourths of the expenditure was swallowed up in works below ground. Of well-sinking alone for brick foundations there was 15,019 lineal feet, or nearly 3 miles.

Arbor.—The term arbor is often used in a very loose manner to signify various spindles used in connection with machine tools, some of which designations are not generally accepted, but are due to the fancy of workmen, or writers. Thus nearly all classes of driving spindles have been in turn called arbors, though they should for clearness be termed spindles, or sometimes, as in the case of lathes, mandrels. Mandrels which are driven from the main spindle and carry work, such as lathe mandrels and gear wheel mandrels, are also frequently designated arbors. But the more correct meaning and the one generally employed is that which denotes

	Solani Aqueduct.	Nadrai Aqueduct.
River waterway - - - -	13,000 sq. ft.	21,000 sq. ft.
Canal waterway - - - -	1,600 sq. ft.	1,040 sq. ft.
Canal discharge - - - -	6,780 cub. ft. per sec.	4,100 cub. ft. per sec.
Number of arches and spans - -	15 of 50 ft.	15 of 60 ft.
Width between faces of arches -	195 lin. ft.	149 lin. ft.
Length - - - - -	1,170 lin. ft.	1,310 lin. ft.
Depth of foundation below river bed -	19 ft.	52 ft.
Total height of structure - -	56 ft.	88 ft.
Cost (in rupees) - - -	33 lakhs	$44\frac{1}{2}$ lakhs.
Time taken in building - -	7 years.	4 years.

PLATE VIII.

Fig. 113.—Laying the Last Line of 48-inch Pipes of the Manchester-Thirlmere Aqueduct in the Scardale Valley (1904).

To face page 162.

the separate spindle-like fittings which carry milling cutters, hollow (or shell) reamers, and shell drills. Those which hold grinding wheels are termed by some arbors. These will be treated more properly under **Grinding Wheels**, and **Grinding Machines**.

The machine spindle, if prolonged, would serve for the duty of carrying milling cutters, &c., but it is not desirable to do this, because only one size and style of the arbor portion would then be available. Separate detachable arbors are therefore employed and designed to suit the various sizes and types of cutters being used. Another application of the word is that in connection with small chucks. *See* **Arbor Chuck** for this.

Though the mandrels which carry work in the lathe and other machines are classed as arbors by some, to avoid confusion with the present subject they will be treated under **Mandrel**, the more common and correct designation.

The arbors which carry and drive cutters may be supported at one or at both ends, and in the case of specially long ones at one or more intermediate positions. The simplest types, supported only at the end, are those employed for end (or face mills), for shell reamers, and shell drills. These tools are held thus in preference to being made in the solid with arbors of their own, for obvious reasons, the chief among which is the saving of expensive steel. By providing a set of arbors, a large number of different cutters may be accommodated, and the latter will use up no more tool steel than is requisite to afford the proper shape and strength. The unnecessary multiplication of shanks is saved, a small number of arbors being required. The smaller sizes of cutters and reamers, &c., are, however, made solid with their shanks.

The ends of arbors which fit into the machine-driving spindles are almost invariably of tapered form, ensuring true running, and automatic take-up of slackness due to wear, which is not the case with screwed or plain parallel shanks. A typical form of arbor fitting in the first-named manner is shown in Fig. 114, the cutter being in dotted lines. The mill A is held on the parallel portion and driven by a square key, and the screw in the end of the arbor retains the cutter in place.

There are several variations upon this standard design; a round pin is frequently used instead of the rectangular key, the pin fitting half way into the arbor and half way into the cutter. This method is simple, the pin being readily cut from rod, and the recesses do not weaken the arbor and mill so much as a square - cornered groove does. Another very common mode of driving is that of keys or clutch jaws upon the shoulder of the arbor, Fig. 115, engaging in a recess or slot across the face of the cutter, and effectually driving it around. For shell reamers and drills this device is the most usual, because there is generally a short plain portion at the back of the tools through which the slot may be cut. Shell reamers are also fitted with a taper hole upon their arbors, so that the closeness of fit is preserved. A difference between reamer and drill arbors is that they are much longer than those for mills, to reach into deep work, where an unsupported mill would not be used. Reamer and drill arbors also frequently have parallel shanks like those of the solid tools, with perhaps a square as well on the end.

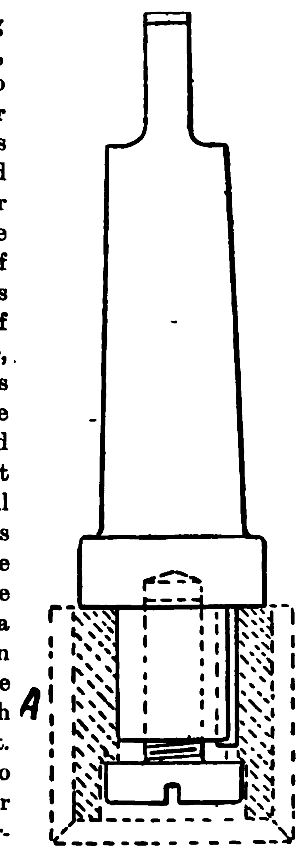

Fig. 114.—Arbor for End Mills.

An exception to the use of keys or clutch jaws occurs in the arbors for small slitting cutters or saws, which fit upon a plain portion, and are clamped and driven between a couple of washers tightened with a nut, the friction of the

washers being ample to drive the thin cutter against its work without slipping round on the arbor. In some cases milling cutters are attached to their arbors by screwed holes, but this is not so reliable as the more usual plain shank, from the point of view of concentric running.

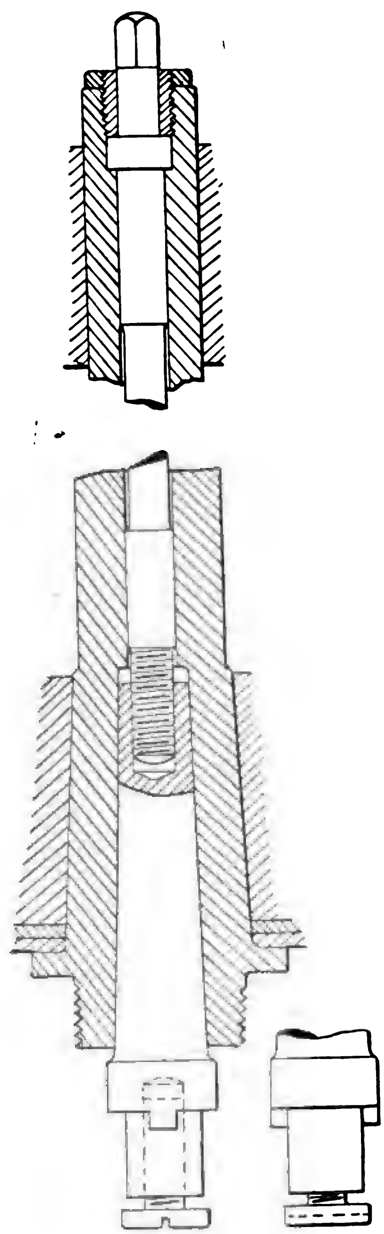

Fig. 115.—Arbor with Clutch Pieces, and Long Spindle Bolt.

The taper fitting of the arbor shank in the machine spindle is only sufficient to drive the arbor under light cuts, so that various auxiliary devices are employed for heavier service. Positive driving is often effected by a flat tang on the arbor end engaging in a slot at the bottom of the taper hole in the spindle in drill fashion, Fig. 114.

An effectual method of retaining a taper shank in place endwise is shown in Fig. 115, a long bolt passing through the hollow spindle and screwing into a tapped hole in the arbor end, so that it is drawn tightly inwards. For heavier work a positive drive is obtained without the use of the tang mentioned (which cannot be employed when the spindle has a hole clear through), by fitting a clutch device. Slots are cut across the face of the spindle, and projections on the arbor engage in these, carrying the arbor round positively. Sometimes when large cutters are used, jaws on their back mesh with the spindle recesses, relieving the arbor of the duty of driving.

A form of arbor differing from any of those already mentioned is that for fly cutters—single flat pieces of steel. These are held in a slot at the arbor end, and pinched with set screws.

We have up to now only considered those types supported at one end. The uses of these are very extensive, but they are limited to end cutting, and short lateral widths in milling, though for reaming and drilling the single support is in most cases sufficient. But for surface milling, involving the use of an arbor projecting out some distance, supplementary support must be afforded to keep the cutter up to the work and prevent chatter. A point centre, like that of a lathe poppet, may be located to go into a countersink in the arbor end, but this device is not much used because the small area of the point does not secure the arbor from vibration when in service. A better method is to support an adequate length of the end with an encircling bearing, which must be provided with means of adjustment to take up slack. One method of doing this is to make the arbor end tapered, so that the bearing hole (of corresponding taper) may be pushed over until the lateral slackness is *nil*. Both this and the point centre are open to the

objection that no allowance is given for endlong expansion of the arbor, due to its heating when at work, and it therefore tends to warp to a curve, with bad results upon the work. A better and more common device is therefore that shown in Fig. 116, in which the parallel end of the arbor at A runs in a bush B, which is split partly through the side, and has a bevelled edge at the end. The act of tightening up the set screw C draws this bush backwards, the bevelled end causing it to close inwards around the arbor portion A, so taking up lateral slackness, while still permitting of free endlong play.

This system of support is not always practicable, because it often happens that it is desirable to pass the arbor right through the bearing, to bring the latter close up to the cutters, and minimise vibration. In such cases a thoroughfare bearing is employed, having a split bush tapered on the outside to draw into its bearing bracket, in the same manner that various spindle bearings are fitted. This is shown in Fig. 117, the split bush being adjusted by means of encircling nuts on either side. This illustration also gives a method of driving the tapered arbor end with a key, and a cottar to draw the arbor up to place. It represents a type used for heavy service on plano-millers.

A third supporting bearing is frequently used for an arbor, when the latter is long, and perhaps rather slender, and has a number of cutters fixed upon it. To enable these to stand up to the cut without vibration, an arm or bearing is introduced at or about the middle of the arbor, between a couple of the cutters. If this were not done it would be in many cases necessary to provide a stiffer arbor, of larger diameter, which would often be undesirable or impossible.

The methods of driving the cutters on long arbors are similar to those already described.

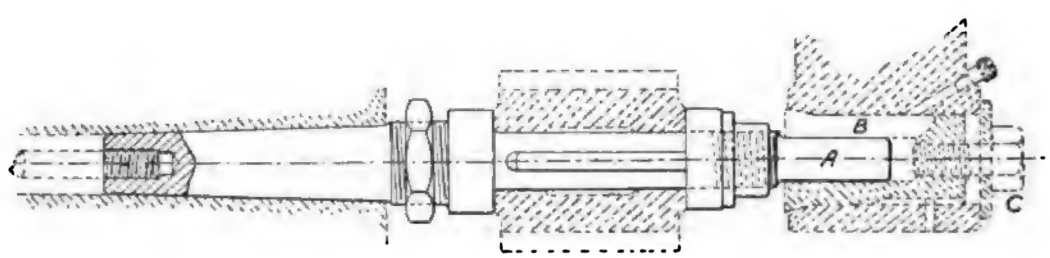

Fig. 116.—Arbor supported at both ends.

Washers or collars also are necessary for separating the various cutters, and retaining them in fixed positions laterally, as seen in Fig. 116. Adjustable collars are also common, having provision for obtaining minute differences in thickness, where accurate sizing between edges has to be done, and compensation effected after grinding cutters.

The methods of removing arbors are usually by the nuts seen in Figs. 116 and 117, next the spindle face. In small machines the arbor is frequently knocked out with a rod passed through the hollow spindle. If the draw-in bolt, shown in Fig. 115, is employed, it also serves to thrust out the arbors by turning the bolt in the reverse direction.

Arbors are not always fitted direct to their spindles, but intermediate sockets or sleeves are used, just as in the case of drilling machines.

The two essentials in an arbor are accuracy

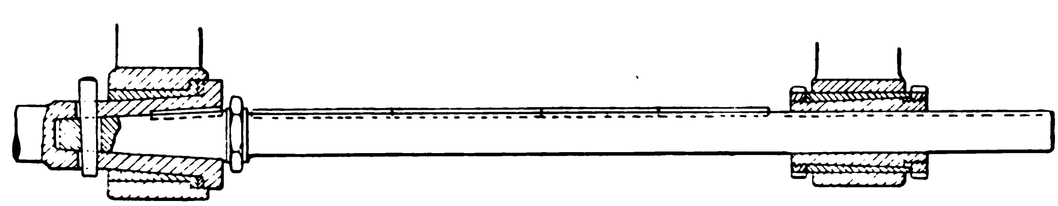

Fig. 117.—Arbor supported at both ends.

of running, and rigidity, the absence of either of which will result in faulty work being produced. But the two are intimately connected, since an arbor may be finished to run ever so truly, and yet, through slenderness, may spring when at work, so allowing the cutters to run out of truth when cutting. Excellence of

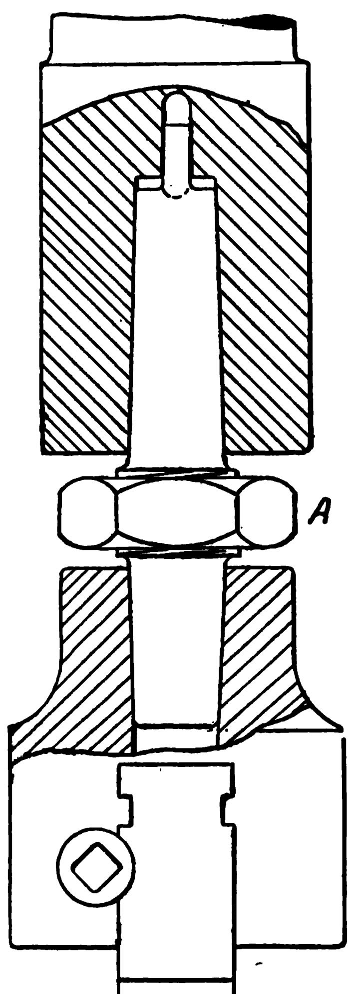

Fig. 118.—Arbor Chuck.

workmanship is therefore of no avail unless the arbor is of ample diameter to remain rigid against the pressure of the cut, which is very severe in many cases. Accuracy of running is secured by the employment of the cylindrical grinding machine for finishing the arbors. The faces of shoulders, collars, washers, nuts, and cutters must also be ground square across to guard against the springing of the arbor which would result from the tightening up of inaccurately faced parts upon it. Cleanliness must also be observed to obtain the best results; no dirt or grit should be permitted between the surfaces of the arbor and its fittings, otherwise trouble may be caused.

The importance of securing true running cannot be over-estimated, for want of concentricity means that only two or three teeth of the cutter are brought into action on the work, with consequent lowering of efficiency, and inaccuracy of workmanship, because if excessive feed is put on to make the cutter go in deeply, and operate around its entire diameter, the arbor will spring away in an erratic fashion, with inevitable inaccuracy of the milled surface.

Arbor Chuck.—This term does not denote a chuck having any special form of mechanism for its operation, but refers to the method of attaching the chuck to its driving spindle with an arbor, which fits by a taper into the spindle, and into the back of the chuck, Fig. 118. A nut, A, is usually fitted, by which the arbor may be drawn out of the spindle or out of the chuck, when required.

The device is applied only to small sizes of chucks, for holding drills in lathes and drilling machines, and in chucks for turning—not exceeding about 4 inches in diameter. Above this size the face-plate mode of fitting is adopted. The disadvantage of the arbor method is that it does not allow a clear way through the spindle for long rods, which, though of no account in drills, is desirable sometimes for lathe work. Other methods of attachment, such as the screwed nose, or the face-plate forms, must then be employed, or a different kind of chuck altogether, such as the collet type.

Arbor Cutter.—Applies both to **Milling Cutters**, held with arbors, and to the arboring tool, described under **Arboring**.

Arboring.—This is the name given to the operation performed by the arboring tool, Fig. 119, used for facing off surfaces around holes, for the reception of bolt, screw, and pin heads, &c. The tool is employed in cases where the facing cannot be done upon the drilling machine, owing either to awkwardness, or to the fact

that the holes in the work have been drilled in the erecting shop by ratchet or portable drills, and the quickest and neatest mode of finishing off the facings is by the arboring tool, which is operated by hand.

The circular arbor A has a flat cutter B with two working edges, fastened with a wedge C. At the other end the arbor is screwed down for some distance, and has a groove or spline, as shown. A washer D slides easily over the screw, and is provided with a projecting tongue engaging in the spline. The nut E serves to draw the cutter against the face to be arbored, constituting the feed. The square on the end of the arbor is revolved with a tap wrench, and as cutting goes on, the nut E is given a portion of a turn at intervals, so drawing the cutter up again to a slight extent. This is continued until the face is made square, or is reduced to the depth required. The object of the spline and the tongue in the washer is to prevent the nut from slacking back while turning is going on. If the washer were loose, its pressure against the work face would prevent it from revolving, and the nut would also be held frictionally, so that the screwed arbor would simply run through the nut, and let the cutter get away from its work. But the washer being compelled to rotate with the arbor, also carries the nut around by its friction, so that once set to any position, the nut does not alter its position on the screw. The same effect may be secured by using two nuts (without the washer), locking them upon each other, but this involves more trouble and time in loosening and again locking the nuts against each other, than the simple screwing down of the single nut in the figure does.

An alternative form of cutter to that of flat shape is made as a disc, encircling the arbor, and having teeth upon its face (like a milling cutter). This is more troublesome to make than the plain flat piece, but works rather quicker, owing to the greater number of edges in operation.

Other shapes of cutters are frequently employed, specially those for countersinking, as shown in the figure at *a*, a style which is used where it is impossible to countersink with the drill. Cutters for counterboring also are used, being made of a size across their edges corresponding to the diameter of hole required. They are fed in until the necessary depth is attained. The utilities of the tool are not confined to flat surfaces; it is only a matter of forming the cutter outline to the desired profile, to finish

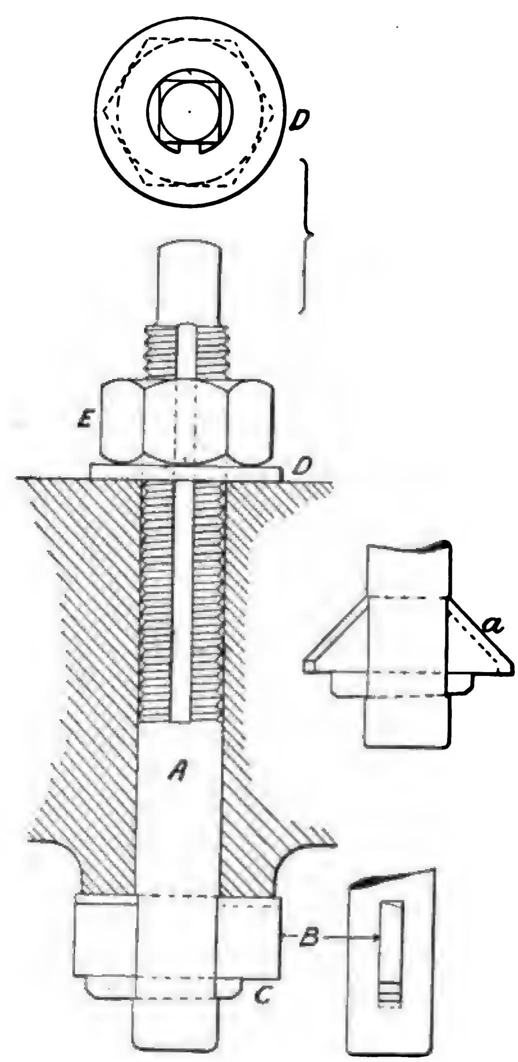

Fig. 119.—Arboring Tool.

curves, or combinations of curves, with straight edges.

A set of these arboring tools is usually kept in the erecting or fitting shop, ranging in standard diameters of holes in common use. All the portions should be hardened, to enable

them to stand the severe service which they have to endure. Allied to these simple tools are the large group of **Facing Tools**, having similarities in form and function, which will be found treated under the heading just mentioned.

Arbor Press.—*See* **Mandrel Press.**

Arc (Lat. *arcus*, a bow).—An arc is any part of a curved line, and an arc of a circle is any

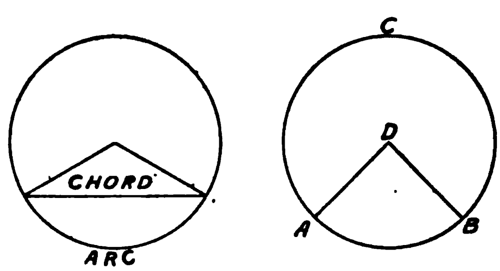

Fig. 120.—Arc of Circle.

part of the circumference. The straight line joining the ends of an arc is called the chord, and is obviously less in length than the arc itself. In Fig. 120 the angle ADB is spoken of as the angle subtended at the centre of the circle by the arc AB. If the number of degrees in this angle is known, and the length of the circumference, it is possible to find the length of the arc. For whatever fraction of 360° (the number of degrees in a circle), the given angle is, the arc will be the same fraction of the circumference. Or, referring to the figure :—

As 360° : angle ADB : : circum. ACB : arc AB.

For example, suppose the circumference is 144 inches, and the angle subtended by the arc is 45°. The length of the arc will then be :—

$$360^\circ : 45^\circ :: 144 : x$$

$$x = \frac{144 \times 45}{360} = 18 \text{ inches.}$$

Or the number of degrees in the angle may be found if the length of the arc and the circumference are known. Whatever fraction of the whole circumference the given arc may be, the angle is the same fraction of 360°. Thus in the figure :—

Circum. ACB : arc AB : : 360° : angle ADB.

Suppose the circumference of a circle be 68 inches, and it is required to find the number of degrees in an angle subtended by an arc 17 inches in length. Then, according to the rule just stated :—

$$68 : 17 :: 360^\circ : x$$

$$x = \frac{17 \times 360}{68} = 90^\circ$$

Arch.—The arch occurs in many forms, is utilised in many ways, and built in various materials. The mathematics of the arch are both abstruse and unsatisfactory. A perfect arch is one in which no slip can occur at abutments, crown, or haunches, from which it follows that the arch can only fail by crushing of the materials. The arch must have sufficient thickness for its curve of equilibrium. If an arch is in equilibrium, the tendency to spread at the abutments is conveniently resolved into a force acting in a horizontal direction equal to that at the crown. Mathematical investigations on this subject generally begin with the assumption that the arch stones possess neither cohesion nor friction upon each other, and that no cementing material is used. Actually these last conditions are of absolute importance, as is evidenced by the great care necessary in the preparation and application of good cement, reinforced by dowels in the abutments. The latter must be strong enough to resist the thrust of the arch without either sliding or crushing.

The parts of arches are named as follows (Fig. 121) :—

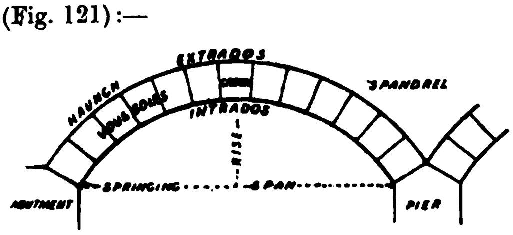

Fig. 121.—Parts of Arch.

The span is the width between abutments, or piers at the line where the arch springs. The rise is the height or vertical distance between the springing, and the crown. This is an important element in design, and one in which the arch of iron or steel possesses advantages over those of masonry, because a smaller rise can be obtained in metal than in stone. The rise necessary for many stone arches is such as to prevent the carrying of a level road

over them. But by the substitution of metal a comparatively flat curve suffices. The intrados of an arch is the inner surface, also termed the soffit. The extrados is the outer surface. The crown is the upper part of the arch, between the intrados and extrados, the haunches are the flanking portions between the springings and the crown. When an arch is built of masonry the wedge-shaped stones are termed the voussoirs, and the upper central stone in the crown is the keystone. Voussoirs give place to arched girders in iron and steel bridges. But some of the early examples of cast-iron bridges were built of true voussoirs, either cast solid, or hollow. The difference between an abutment and a pier is that the first named is that from which the springing of a single arched structure occurs, the latter is the support from which two arches spring. The skewback is the portion of a pier from which a segmental arch springs. Its top face is inclined towards the centre of the arch, similarly to the voussoirs, though its bottom face rests with a horizontal joint upon the pier stones. The sommering lines are radiating lines which correspond with the direction of the bed joints of the voussoirs. The spandrels are the areas which lie between the haunches of adjacent arches. These in iron bridges are made the subject of ornament.

The principal classes of arches used in engineering are the semicircular, the segmental, the elliptical, Fig. 122, the three-centre arch, and the parabolic. The pointed form, the groined arch, and the so-called straight arch, concern work in masonry. The cambered arch is used in aqueduct work. The skew arch may be either of semicircular, segmental, or elliptical section.

Since the introduction of steel for bridges a form of arch has been used in many cases, that termed the pivoted. The object of pivoting is to provide for the rise and fall of the metallic arch with variations of temperature. Even yet the utility of this design is open to question. There are many arched bridges of considerable span which are rigid. The largest cast-iron arched bridge in France, the Pont St Louis, with a span of 210 feet, is rigid. Two railway bridges over the Trent, of 200 feet span, are also rigid, as are two recent bridges over the Rhone at Lyons, although the central spans are 221 feet in length. The pivoted arches are in some examples pivoted both at the springings, and at the crown, in others at the springings only, and continuous over the crown. These latter are the most numerous. The Douro Bridge is an interesting example of this class. Another is the Harlem River Bridge. Another is the Pont de Midi Bridge. The advocates of rigid arches pin their faith on the elasticity of the lattice girder ribs, of which such arches are now generally built. Those who advocate pivoted arches say that a considerable saving in metal is possible by the adoption of this design. The effects of temperature set up more severe stresses in the rigid structure than in the pivoted type, which have to be met by increased metal.

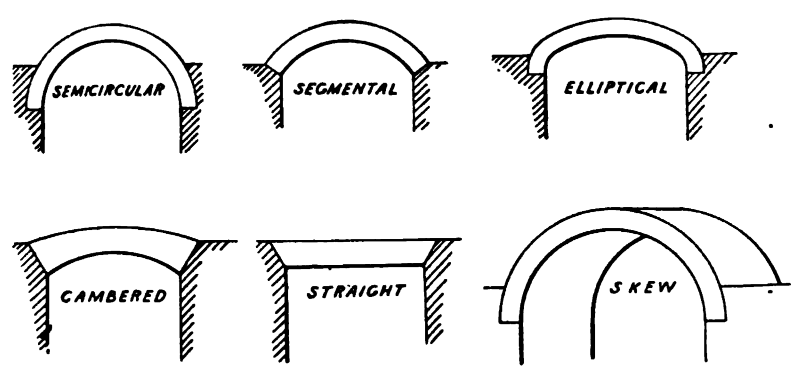

Fig. 122.—Forms of Arches used in Engineering.

For examples of arched structures, *see* **Bridge, Roof.**

The arch occurs in structures other than

buildings, in the various furnaces for solid fuel, and gas, and in the **Brick Arch** of locomotives.

Archbutt-Deeley Process.—A process of water softening due to Messrs Archbutt and Deeley, which permits of a reduction of tank area to about one-sixth of that required by Clark's process, and of the omission of the filters generally used therewith, so reducing the cost of softening. It is adopted for water for steam-raising in many different works, and also for laundries, dyeing, bleaching, &c., in addition to an installation at the Midland Railway Works at Derby, where it has been in operation since 1891. Using the water of the river Derwent, the hardness is reduced from about 15 to 4½ or 5 degrees, besides effecting almost complete purification from bacteria, and all at an inclusive cost for chemicals, labour, and interest on outlay, of about 1d. per 1,000 gallons.

The two features by which this system is distinguished from others are, an arrangement for disturbing the precipitate obtained from the previous softenings of the hard water, mixing it again mechanically with the water, and the bicarbonisation of the softened water. Lime is added for softening hard water, in order to remove the carbonic acid dissolved in the water, combining with it to form carbonate of lime, which is precipitated. The carbonate of lime previously held in solution by the carbonic acid is also precipitated. The temporary hardness is removed, but the precipitates take a long time to settle in the ordinary methods in use, hence the reason for the use of large tanks or of filters. In the Archbutt-Deeley process the settlement is hastened by stirring up some of the precipitate which has settled from previous operations, as often as a tankful of water is softened. The effect of stirring up this sediment, which exists in coarse flakes, is to carry down the fine particles of fresh precipitate rapidly, so that in from half an hour to an hour the water is cleared so effectively that the suspended matter, which remains even to a depth of 6 feet from the surface, does not exceed about a grain per gallon. The precipitate is prevented from accumulating unduly in the tanks by removing portions of it at regular intervals. The following table gives an analysis of Derwent water before and after softening:—

	Grains per Gallon. Unsoftened Water.	Grains per Gallon. Softened Water.
Carbonate of Lime	9·90	2·63
Carbonate of Magnesia	0·78	
Sulphate of Lime	3·06	0·17
Sulphate of Magnesia	2·89	1·67
Sulphate of Soda	0·41	5·10
Common Salt	2·56	2·64
Nitrate of Soda	0·28	0·28
Silica	0·34	0·34
Water not expelled at 206° Fahr., Organic Matter, &c.	1·78	1·37
	22·00	14·20
Degree of Hardness (Clark)	15·4	4·14

The following table is an interesting instance of a very hard well-water, strongly impregnated with magnesia, which is being successfully softened at Nottingham:—

	Grains per Gallon.
Carbonate of Lime	9·19
Carbonate of Magnesia	1·4
Sulphate of Lime	12·17
Sulphate of Magnesia	7·05
Nitrate of Magnesia	13·69
Chloride of Magnesium	0·64
Chloride of Sodium	6·3
Silica	·62
	51·06

Temporary hardness, 10·9 degrees; permanent hardness, 24·6 degrees; or a total hardness of 35·5 degrees.

After treatment, at a cost for chemicals of about 2½d. per 1,000 gallons, all the permanent hardness is removed, and the temporary hardness is reduced from 10·9 to 3·2 degrees. The softened water is used for wool-washing and steam-raising; it forms no scale in the boiler, and the economiser tubes are kept free from incrustation.

The illustrations, Figs. 123-125, are those of a recent plant at Ilkeston by Messrs Mather & Platt, Ltd., of Salford. It consists of a tank divided into two portions fitted up in exactly the same manner, so that the processes of filling, softening, and clarifying are being carried on in one, while the softened and clarified water is

being drawn off from the other. The number of tanks varies with the requirements. For 3,000 gallons per hour, and less, one softening, and one storage tank suffices; for more than 10,000 gallons, three or more tanks are desirable. The tables give sizes of tanks for various requirements of supply.

TABLE I.—DIMENSIONS OF SINGLE TANK

Capable of being filled or emptied in 20 minutes, allowing 1½ hours for treating and settling, for various quantities.

(MATHER & PLATT, LTD.)

Capacity of Plant, Gallons per Hour.	Approximate Dimensions of Tank in Feet.	Gallons of Hard Water required per Minute.	Inlet Pipes, Diam. in Inches.	Outlet Pipes, Diam. in Inches.
1,000	8 × 8 × 8	120	4	4
3,000	12 × 12 × 10	360	6	8
6,000	18 × 18 × 10	760	9	10

TABLE II.—NUMBER AND DIMENSIONS OF TANKS

Capable of being filled in 20 minutes, and of giving a continuous delivery, allowing 1½ hours for treating and settling, for various quantities.

Capacity of Plant, Gallons per Hour.	Number of Tanks.	Approximate Dimensions of each Tank in Feet.	Gallons of Hard Water required per Minute.	Inlet Pipes, Diam. in Inches.	Outlet Pipes, Diam. in Inches.
1,000	2	8 × 6 × 8	90	3	3
3,000	2	12 × 10 × 10	300	6	3
6,000	2	16 × 14 × 10	560	8	4
10,000	2	20 × 20 × 10	1,000	10	5
15,000	3	18 × 16 × 10	720	9	6
25,000	3	24 × 20 × 10	1,200	12	8
30,000	3	26 × 24 × 10	1,462	12	9
40,000	4	24 × 24 × 10	1,350	12	10
60,000	4	28 × 28 × 10	1,857	14	12

In cases where the available supply is only just equal to the demand, larger tanks, or a greater number of the size given, are required. The sizes of inlet pipes are approximate.

In the illustrations, the hard water is admitted to either tank by means of the supply pipe, to the level of a gauge mark on the side of the tank. At the same time the lime and carbonate of soda are weighed, and boiled in the chemical tank by means of live steam. When filled to the level of the gauge mark, the inlet valve is closed, and steam is admitted to the blower, causing a current of water to circulate up through the rose, the three-way tap, down the vertical pipe, and back into the tank through the perforations in the upper row of horizontal pipes. The three-way tap is then opened, and the prepared chemical solution is slowly drawn into the circulating current, and diffused through the water in the tank.

The air tap is next opened to admit air through the pipe at the top of the blower, and the air is blown for a few minutes into the treating tank through the upper pipes. Then by reversing the three-way tap, the air is forced through the perforations on the under side of the lower row of pipes. From thence it rises in streams of bubbles, stirring up some of the precipitate left in the bottom of the tank from previous operations.

After the blower has been in operation for about ten minutes, which period varies with different waters, the steam is turned off, and in about an hour nearly all the precipitate will have settled to the bottom of the tank. The water, even to a depth of 6 feet from the surface, will not contain on an average more than about one grain per gallon of suspended matter.

As uncarbonated softened water, by whatever process obtained, is liable to form a deposit in pipes, the bicarbonising process just now alluded to, is accomplished as follows:—

The operations of carbonating and drawing off are simultaneously performed automatically by means of a hinged pipe of rectangular section (one is seen in each of the tanks) the mouth of which is kept just below the surface of the water by means of floats. Fuel gas from a coke stove is forced continuously by means of

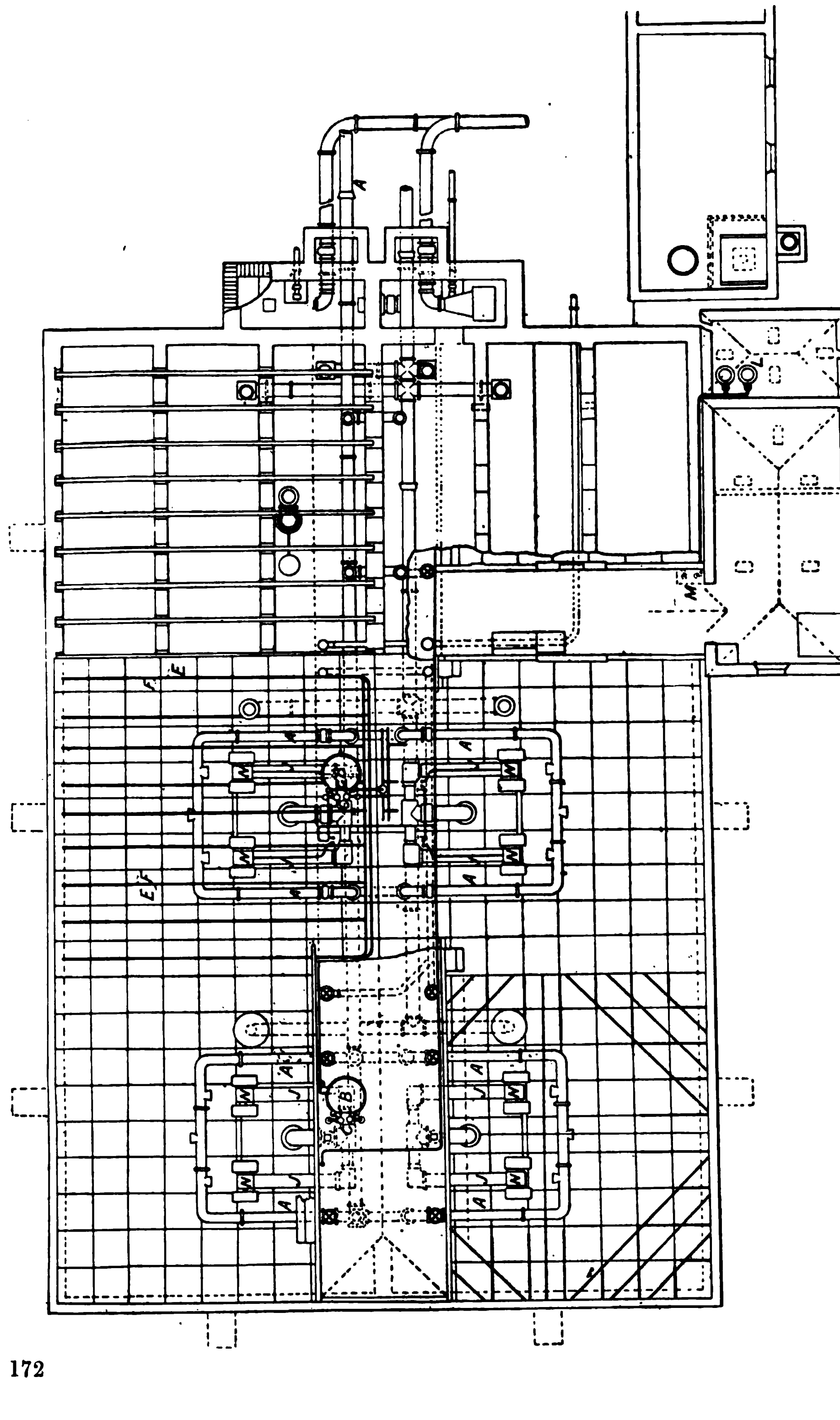

Fig. 123.—Water-Softening Plant at Ilkeston. (Plan View.)

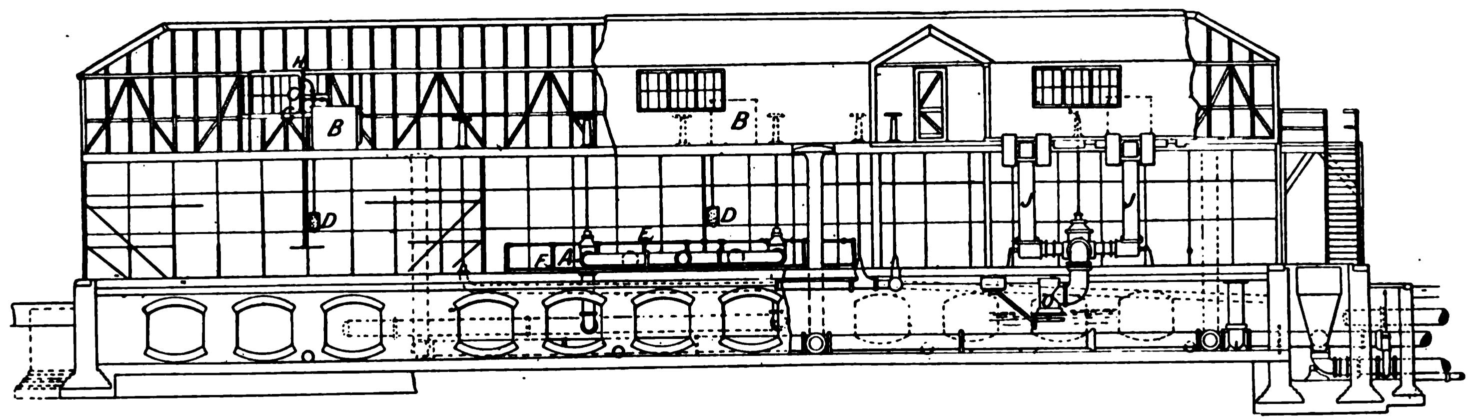

Fig. 124.—Water-Softening Plant at Ilkeston. (Longitudinal View.)

REFERENCES TO FIGS. 123-125.

A. Hard Water Supply.
B. Chemical Tank.
C. Blower for Air and Mixing Chemicals.
D. Perforated Rose.
E. Upper Perforated Pipes.
F. Lower Perforated Pipes.
G. Three-way Tap to Chemical Tank.
H. Air Tap on Blower.
J. Floating Discharge Pipe.
K. Carbonating Pipe from Coke Stove.
L. Coke Stove.
M. Blower for Fuel Gas.
N. Discharge Mouth.
O. Ball Tap for Regulating Outlet.

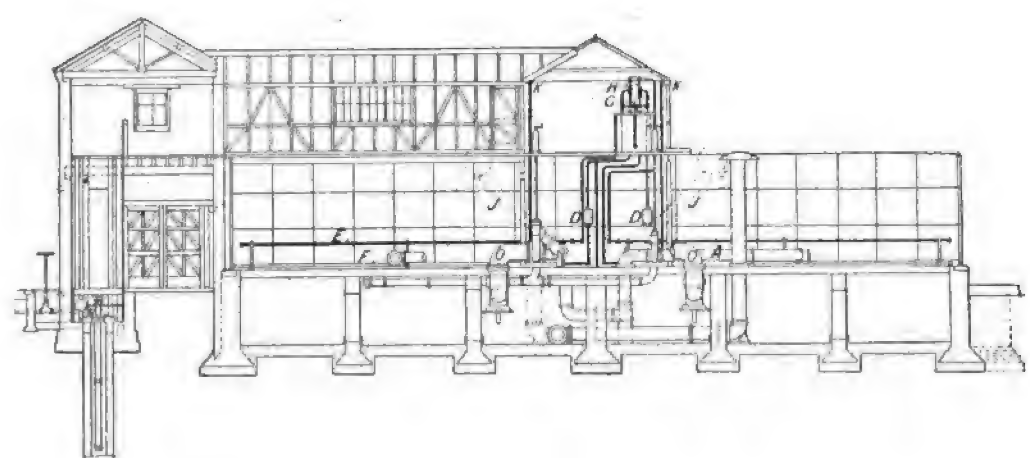

Fig. 125.—Water-Softening Plant at Ilkeston. (Transverse View.)

a small steam blower up the pipe, escaping by the discharge, and being caught by the descending current of water. This water in flowing down the pipe is repeatedly splashed upwards by baffles fixed at intervals along the bottom. The fuel gas is carried along with the water through a ball tap fixed over the small supply tank into which the carbonated water falls, while the residual nitrogen, &c., of the fuel gas escapes into the air. If the ball tap should close by the filling up of the tank, the gas escapes through a vent pipe. A gauge mark on the side of the softening tank about 2 feet from the bottom indicates the level below which the water is not drawn off. Just before the water reaches this level, a rest on the bottom of the tank prevents the further descent of the discharge pipe.

In case objection should be taken to the presence of sulphur in the coke, Messrs Mather & Platt, Ltd., point out that, even assuming the coke to contain 2 per cent. of sulphur, and if all were oxidised to sulphuric acid, the quantity of sulphuric acid per gallon of water would be only 0·055 grain. But as the softened water of three degrees of hardness contains fully fifty times as much alkali as is required to neutralise this amount of acid, the sulphur in the coke is absolutely negligible.

The cost of softening water varies. If carbonate of lime alone has to be removed, the lime required is so cheap that the expense is small. To remove sulphate of lime, carbonate of soda is used, which is more expensive. Magnesium salts require caustic alkali, which is the most costly. The following table affords an approximate guide in estimating the approximate cost of softening different waters.

TABLE SHOWING THE VARYING CHARACTER OF WATER FROM DIFFERENT SOURCES, AND THE CONSEQUENT DIFFERENCE IN THE COST OF SOFTENING. (MATHER & PLATT, LTD.)

SOURCE	Well	River	River	River	Canal	Well	Brook	Well	Disused Shaft	Clay Pit
	GRAINS PER GALLON.									
Calcium Carbonate (Carbonate of Lime)	10	8·74	13·15	16·39	10·99	9·19	2·06	9·41	8·3	1·39
Magnesium Carbonate	4·76	2·78	·33	·31	2·76	1·4	·94	1·	2·82	1·78
Sodium Carbonate	4·19	...	...	...	...	...	...	...	...	...
Calcium Sulphate (Sulphate of Lime)	...	3·26	...	4·3	2·99	12·17	47·34	22·91	40·61	54·14
Magnesium Sulphate	...	...	1·96	1·28	12·41	7·05	5·7	15·9	22·25	22·46
Sodium Sulphate	4·15	1·44	·3	...	18·96	...	9·98	...	2·65	28·96
Magnesium Nitrate	...	...	...	...	...	13·69	...	11·5	...	...
Sodium Nitrate	...	...	·96	small	...	...	...	...	small	...
Magnesium Chloride	...	...	...	...	...	·64	...	2·08	...	...
Sodium Chloride	1·65	2·72	2·06	3·05	5·28	6·3	6·77	5·05	6·35	5·28
Silica	...	·43	·39	·42	·31	·62	·62	·9	·84	·36
	24·75	19·37	19·15	25·75	53·7	51·06	73·41	68·75	83·86	114·37
Total Lime (CaO)	5·6	6·24	7·36	10·95	7·39	10·16	20·64	14·7	21·39	23·07
Total Magnesia (MgO)	2·28	1·33	·81	·58	5·48	7·02	2·36	9·82	8·81	8·38
CALCULATED HARDNESS (*i.e.* Total Lime and Magnesia, calculated to Carbonate of Lime)	15·65	14·5	15·16	20·99	26·77	35·53	42·7	50·57	60·02	61·95
Approximate Cost of Chemicals required for softening 1,000 gallons	0·2d.	0·5d.	0·4d.	0·6d.	1·2d.	2d.	2·8d.	3·1d.	3·6d.	4·2d.

NOTE.—The above estimates of cost are based upon the following prices, viz. :—

Quicklime	£1 per ton	58 °/o Alkali	£4 per ton

Arched Beam.—Beams of timber, cast iron, or steel arched in form, differ from voussoirs, and from tied beams. *See* **Arch, Beam, Bridge, Roof.**

Archimedean Drill, or **Persian Drill.**—A drill stock which is rotated by the movement of a nut along a multiple-threaded screw of quick pitch. The form is familiar. In engineers' shops it is occasionally used for centring light spindles to be turned between centres.

Archimedean Screw.—A particular form of the screw, the invention of which is attributed to Archimedes, for raising water from the hold of a ship built by Hiero. It is probably little used for water-raising now, but the principle is adopted more than ever in some conveying systems. The screw comprises a helix of many turns around a body or core, and is itself surrounded by a cylinder fitting it closely. The result is that when the screw is set at an inclination in the water and rotated, the water is compelled to rise around the spiral and so be drawn out at the top. Pumps have displaced these from this particular function. But enclose the continuous screw in a shoot, or cylinder, or trough, and a most valuable piece of mechanism is provided. These exist in many forms, are cast solidly, or built up, and used for the conveyance of corn, malt, seeds, cement, ores, phosphates, coal, &c. These will be found described under **Screw Conveyors.**

Architecture.—The tree-trunk may be regarded as the early origin of the five orders of Architecture. The Greeks were indebted to the Assyrians and Egyptians for their first notions of columnar edifices, but there is no doubt that the column with its base and capital represents a very highly elaborated form of a trunk supporting the roof of a hut. Similarly the concave roofs of Chinese houses and pagodas are but a development of the tent of the early nomadic Tartars, while the massive sloping walls and flat roofs which characterise Egyptian architecture are akin to the heavy mud walls of the earliest inhabitants.

The rough and massive type of Architecture adopted by the early Greeks gradually, however, developed into lighter, more delicate, beautiful and highly decorated forms, and the terms Doric, Ionic, and Corinthian represent successive developments of the stone column during a period of about four hundred years. For the Tuscan and Composite orders we are indebted to the Romans; the former originated in the north of Italy, and the latter was a combination of Corinthian and Ionic. The Doric order has been likened to the male form, owing to the relation between the proportions of diameter and height of its columns. A man is six times

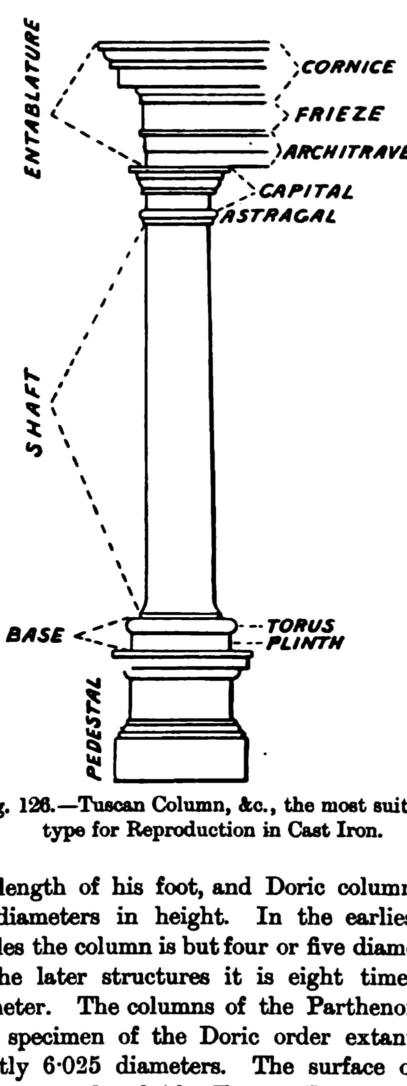

Fig. 126.—Tuscan Column, &c., the most suitable type for Reproduction in Cast Iron.

the length of his foot, and Doric columns are six diameters in height. In the earliest examples the column is but four or five diameters; in the later structures it is eight times the diameter. The columns of the Parthenon, the best specimen of the Doric order extant, are exactly 6·025 diameters. The surface of the column was fluted (the Tuscan, Fig. 126, being the only order of the five in which the surface is plain), the number of flutes being twenty. They were elliptical, and shallower than in the Ionic column, and their curves met with a sharp

edge. The capital was plain, and the order was characterised by breadth, boldness, and harmony. The Parthenon is the best and most perfect specimen of Doric architecture. It was erected in the time of Pericles by the three great masters Phidias, Ictinus, and Callicrates, and would still be in nearly perfect condition had not a bomb burst in its interior when the building was being used as a Turkish magazine in 1687. The Temple of Jupiter at Olympia, and the Temple of Theseus at Athens are other fine specimens of this order.

Just as the Doric order has been compared with the male form, so the Ionic has been likened to the more delicate and graceful female form. The column is here eight or even nine diameters in height. The shaft has twenty-four flutings, each semicircular and separated by a square instead of an angular edge, as in the Doric order. These flutings are, moreover, terminated at the top and bottom by a final curvature. The main difference is in the capital, which consists of two parallel spiral scrolls termed "volutes" which exceed both the diameter of the column and the breadth of the architrave. The distance between the columns is about twice their diameter, and the entablature is barely a quarter of the column's height. The marvellous Temple of Diana at Ephesus—one of the seven wonders of the world—ruthlessly destroyed by the Goths in the year 262, was built in the Ionic order. The most perfect existing specimen is the Erectheus in the Acropolis at Athens.

The last of the Grecian orders was contemporaneous with the decline of Greece. The purity and simplicity of the Doric order had given place to the florid, excessively delicate, and over-ornamented Corinthian style. The base was more complicated; the fluted shaft equalled ten diameters (as compared to five or six in the Doric); the capital was shaped like an inverted bell, or expanded calyx, the surface of which was ornamented with rows of acanthus leaves and scrolls. The choragic monument of Lysicrates is the only specimen in existence.

When the Romans conquered Greece, their luxurious taste found preference in the elaborate Corinthian order. The Doric and Ionic were also adopted with modifications, but to a much less extent. The Composite order was invented by combining the Corinthian and Ionic. Their own type—the Tuscan—was in reality a variety of the Doric architecture with unfluted columns and without triglyphs. The column measured seven diameters, while an astragal was placed below the capital.

Pure architecture finds but a limited place in engineers' work, because the beauty of ornamentation of stone cannot be reproduced except in a bastard form in metal. When architecture is wedded to engineering, it is in the form of stone, brick, or concrete employed in public works, in which the architect is called in to aid the civil, or mechanical engineer. It is no longer then work in metal.

Numerous incongruities have been perpetrated in the vain attempt to embody the ideals of ancient architecture upon new materials. The architect has to make his designs harmonise with the material in which he works. An engineering structure need not be ugly because it is made in cast iron or in rolled steel. But the design is an abnormal and inconsistent one when the attempt is made to graft upon it the beauty of the architecture that was derived from and received its highest elaborations in wood and masonry. There is a feeling that architecture and engineering have little in common, and that the canons which apply to structures in stone cannot be altogether applicable to those in metal. At the present period, therefore, beauty is sought to be attained by the employment of severely simple outlines which are in harmony with the metals used, and the utilitarian character of the works of the engineer.

Even the physical characteristics of the various kinds of metals should in strictness have their illustration in the works executed in them. Forged work cannot be too elaborated in its curves. But such detail seems incongruous in cast iron. Extreme tenuity in this brittle material is not consistent with strength, hence corresponding parts which are entirely beautiful, and in harmony when forged, must be enlarged or blunted, or entirely obliterated in cast. Hence many a piece of cast-iron work meant to imitate malleable iron is an eyesore, depressing to engineer and artist alike. When the

attempt is made to embody the designs of malleable metals in cast iron the inevitable result is clumsiness. The difference between scroll work of all kinds, for brackets, panels, gates, and so on, when built up in curves in wrought iron, and when cast, is painfully noticeable. The first is both light and strong. The second can only be made strong enough by the sacrifice of lightness. The difference is due to the physical characteristics of the materials; malleable metal, which can be bent double without a fracture, and cast iron that cannot be bent at all, but will break with a sharp blow. These facts indicate the sharpness of the division between the two, and determine the proper place of each in design. The fact must also be borne in mind that cast iron is very strong to resist direct pressure, but very weak to resist tensile or bending stresses, while malleable metals are of nearly equal strength for pressure and tension.

The architecture of cast iron therefore properly lies in massive structures which are subjected to stresses tending to crush; that of malleable metals in structures that have to resist both kinds of stresses, or for simple ornament. Yet another distinction too often neglected in design, and sometimes with disastrous results, is that the strength of cast iron is not nearly so uniform as that of malleable iron or steel, since it is not that of the absolute strength of an isolated test specimen, but of an entire casting, which must be generally expected to have very different values of strength in various sections. Malleable metals can be safely forged or rolled with thick and thin sections in proximity, but neither cast iron nor steel can be made with great adjacent disproportions without material sacrifice of strength and safety.

The place of cast iron, therefore, lies (speaking only from the point of view of architectural effects) in the production of columns and pillars, of stanchions and brackets, of bases and entablatures, and railings, where mass is not objectionable. Columns with plain or fluted shafts, and plain mouldings in bases and capitals, can be made of pure classic designs, though purity of design is scarce in the castings supplied by firms. Diameters are too slightly proportioned to length, and bastard ornaments are frequently included that have no place in classic art. Though Corinthian capitals present difficulty in making, the mouldings of bases and capitals are not very troublesome, neither are the details of entablatures.

Within the canons of good taste and severe simplicity of form there is an infinite field in engineering for the judicious employment and blending of curves and straight lines. The classical architectural mouldings in their numerous varieties are adopted more largely than any other kind of ornament, and they harmonise excellently with work in cast iron, and are readily reproduced. But Corinthian capitals are not in very good taste in cast iron, neither are they easy to mould, and when used they are generally cast as separate pieces, and screwed on a plain body. Fluting is correct, pleasing and neat, and presents little difficulty in moulding and casting, hence it is largely employed.

It is fortunate that the judicious and artistic employment of curves in cast iron usually harmonises absolutely with the distribution of metal which is best calculated to afford the maximum of strength. Much of this embodiment of curved outlines has been due in the first place, less to any desire for artistic effect than with the object of securing the greatest strength and safety possible. The realisation of the former or artistic ideal has been a secondary consideration. But by effecting slight modifications in detail, the æsthetic taste has been gratified without sacrificing strength, or employing metal in excess, or embodying harsh or ugly outlines.

The inducement to elaborately ornament work done in cast iron is due to the fact that the moulding and pouring of ornate designs is easy, provided they do not embody much undercutting. If much of the latter occurs, as in the Corinthian capitals just now noted, the moulding becomes tedious and expensive. But no amount of elaboration presents difficulty provided a vertical lift is practicable, hence castings that embody a great deal of ornament are produced cheaply by the firms who lay themselves out for that kind of work. In malleable metals, such work, though practicable, is very costly, and therefore we have an immense number of so-called architectural castings made in imitation

of forged work. At the other extreme of malleable metals we have work of which the lattice bridge is the best type, where nothing but combinations of straight lines occur. In both cases cheapness is the object achieved, consistently with utility.

The modern lattice bridges arouse the ire of architects. But their outlines are in strict harmony with the material used, which is arranged in the forms of ties, and struts, the forces of which operate in straight lines, while the sections of the bars are proportioned very nearly to the actual stresses and strains. Curved outlines in these bars would be inharmonious and costly. Two graceful forms of bridges, the arch, and the suspension, have been largely displaced by the plain lattice types. The arch becomes costly if made in malleable metal, and it is not always reliable for heavy traffic if in cast iron. There are many arched road bridges of the last-named material in existence, but the design is regarded as unsafe for railway traffic. The suspension bridge is also unsuitable for railway traffic, and it is not even safe for heavy road traffic. So that the lattice in its numerous designs of trusses bids fair to remain the only rival to masonry for heavy duty. The cheapness of its construction combined with strength renders its use nearly universal in new bridges. Nevertheless its gaunt bare ribs have no pretensions to architectural effect, but are simply the anatomical embodiment of strengths correlated exactly to stresses and strains, a simple and absolute ideal of the utilitarian. Iron and steel may yet have an architecture of their own creation, even though minds nurtured on the glorious past should be able to give but a half-hearted admiration to the innovations of the new materials. Utility and beauty may properly go hand in hand. Though few but students are aware of the fact, the grandest creations of the architects have been based on utilities. The essentials have come first, and the ornament after. The scope of this subject is far too vast for treatment in a work of this character, but the architect traces it in the infinite details of all structures, from Greek temples to Mediæval cathedrals, the evolution of every member of which is traceable through the ages, and in districts far asunder.

The engineering architecture of the present time comprises chiefly bridges and similar structures, the tall buildings developed in America, great public works as docks, piers, and harbours. In a lesser sense we may consider that architectural effects are embodied in massive engines, in machine tools, and other mechanisms.

The building of structures in stone, and brick, and in concrete is work of a strictly architectural character, and is mostly done in imitation of the ancient Roman models, characterised by severe beauty of outline, and simplicity of ornament, and in composite structures, such as the tall buildings of steel, faced with masonry, and others built after such a model. Arches occur chiefly in the aqueducts, bridges, and dams.

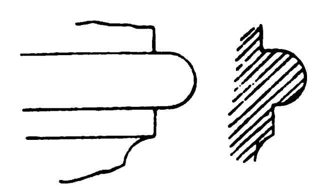

Fig. 127.—Architrave.

The use of armoured concrete appears to be having the effect of substituting the arch for the steel lattice bridge in many cases. The architecture of the tall buildings, and notably that of the Tower Bridge where the real structure is of steel, and the masonry only a covering to hide its gaunt anatomy, has been the subject of severe criticism.

Architrave is a term used in architecture to denote the lowest part of a structure, Fig. 127, supported on columns or pillars. Above the architrave comes the frieze, and above that the cornice, these three portions forming what is called the entablature, *see* Fig. 126. Thus the architrave might also be defined as the lowest part of the entablature. The row of stones immediately above a door or window is sometimes called the architrave.

Arc Lamps.—Arc lamps are those in which there is a bridge, or arc of gaseous matter at a very high temperature, between the ends of two carbon rods. When a gap is made in an electric circuit, a spark passes across the gap, if there is sufficient pressure between the two

sides of the gap to enable it to do so, and with the spark, a minute quantity of the substance of the positive side of the gap is carried over. If the pressure is maintained across the gap, an arc is formed, and will be kept up as long as the pressure remains sufficient.

In the arc lamp two carbons are arranged, usually in a vertical position, one above the other, Fig. 128, and mechanism is provided for separating the two from each other, and for feeding them towards each other as they con-

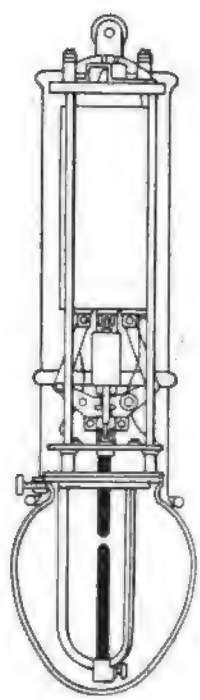

Fig. 128.—General Arrangement of an Arc Lamp, showing the Carbons separated, the Feeding Mechanism above, and the Globe protecting the Arc from the wind, also the Insulated Pulley above for suspending the Lamp.

sume. The continued presence of the arc gives rise to a continued destruction of both carbons, but principally of the positive carbon, and consequently the space between the two ends of the carbon would reach a figure at which the available pressure would not be sufficient to force the spark across. The light given by an arc lamp is principally from a minute crater-like depression in the end of the positive carbon. At this point the greater portion of the heat present in the arc, to which the light is due, is liberated. The carbon is converted into vapour at that point, and some of the former is driven over and deposited on the negative carbon, the remainder forming the gaseous bridge between the two. In addition to the heat liberated at the crater of the positive carbon, a considerable quantity is also liberated in the ends of the carbons themselves, these becoming white hot, and a large amount of oxidation of the carbon goes on there in consequence, this leading to waste of carbon, in addition to that consumed at the positive crater.

The fact that the light is principally given out at the crater of the positive carbon leads to the result that nearly all the light given by a continuous current arc lamp is thrown downwards, the minute crater acting as a reflector for the light rays, and also cutting off a large portion of the upper rays. For a great many purposes, for which arc lamps are employed, this is a good feature. In streets, for instance, and large halls, the light is wanted to be thrown downwards, and it enables the lamps to be placed well up out of the eyes of pedestrians, and of audiences.

With alternate currents, a different set of conditions rules. As explained under that heading, alternate currents are constantly reversing their direction, hence each carbon becomes positive for a very minute period, and negative for a similar period, and so on. Consequently each carbon has its own crater, smaller than that of the positive carbon of the continuous current arc for the same current, but with the result that the light given by alternate arcs is distributed fairly evenly above and below the arc itself. This is not so convenient for a good many purposes, and hence many arc lamps are run with Rectified Currents, that is alternate currents that are turned all in one direction, but which rise and fall in the same way as all alternate currents do.

Arc lamps may be divided into two main groups, the Open Arc, and the Enclosed Arc. The oxidation of the carbon rods mentioned above has led to the development of an arc lamp in which the carbons are screened from the oxygen of the atmosphere. In the Open Arc lamp, the carbons are arranged as already

described, the working mechanism being protected by a metal hood, and the carbons, and the arc itself by a glass globe; but the atmosphere is free to reach the arc. In the Enclosed Arc lamp, the carbons are contained within an inner globe, usually a glass cylinder partially closed at the top, the arrangement being that, when the lamp is first lighted, the arc consumes all the available oxygen within the inner globe, carbonic oxide and carbonic acid being formed. It will be seen that the presence of the inert gas carbonic acid, and the comparatively inert carbonic oxide, reduces the oxidation of the carbons very considerably, and with it their consumption. Hence the life of a pair of carbons in an Enclosed Arc lamp is very much longer than that of a similar pair in an Open Arc lamp, and the mechanism of the lamp itself is very much simplified.

The mechanism of all arc lamps consists of two parts, that designed to "strike" the arc, as it is termed, to separate the carbons, and allow an arc to form between them, and that designed to cause the carbons to advance towards each other as they are consumed. There is a modification of this sometimes used, in which the carbons when at rest, with the lamp not burning, are separated, and the first operation, on switching on the current, is, that the carbons are caused to meet, and are immediately separated, the arc being formed between the separated ends, as with the other lamps. And there is still another modification, recently revived from an old form of arc lamp, but in slightly different guise; the ends of the carbons which are side by side are connected by a piece of metal which is drawn away when the lamp is switched on.

In all cases the mechanism for starting the lamp consists of an electro-magnet, actuated by the current that is to feed the arc, or by some portion of it. The general plan is;—an electro-magnet whose coils are wound with wire of sufficient thickness to accommodate the working current of the arc, is included in the circuit of the carbons, and its armature is made to actuate some form of clutch or equivalent arrangement which raises the upper carbon from the lower. In some lamps, as the upper carbon is raised, the lower carbon is pulled down by a system of pulleys, attached to the upper carbon holder. In the lamps in which the carbons are separated when at rest,—shunt lamps as they are usually designated,—the electro-magnet which brings them together is wound with a fine wire, bridged across, or in shunt, or parallel with the arc. It receives a small current at starting, and its armature overcomes a spring that is keeping the carbons apart, or releases a train of clockwork that accomplishes the same thing. The carbons run together, the circuit is closed, and is immediately reopened, as the shunt electro-magnet loses its current when the

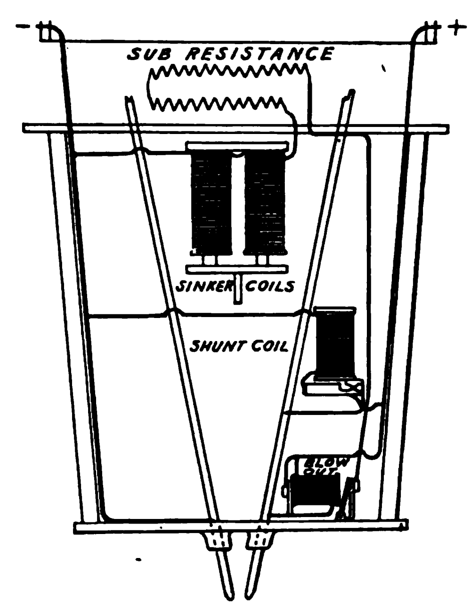

Fig. 129.—Mechanism of the Bremer Arc Lamp. The Carbons are inclined to each other, and are fed by pieces passing down the tubes above. There is a connecting piece between the ends of the Carbons when at rest, which is pulled away by an electro-magnet, on striking the Arc.

carbons are in contact. The spring separates the carbons, and the arc is struck.

The mechanism for feeding the carbons towards each other is various, but is nearly always operated by an electro-magnet, Fig. 129, whose coils are connected as a shunt to, or in parallel with the arc. The strength of the current passing in the feed magnet coils depends directly upon the distance between the ends of the carbons, upon the length of the arc, in fact. When the arc is short, the feed magnet receives very little current, but as it burns longer, the

feed magnet gradually acquires strength, and at a certain predetermined length, the feed mechanism is put in operation, the carbons move towards each other a very short distance,

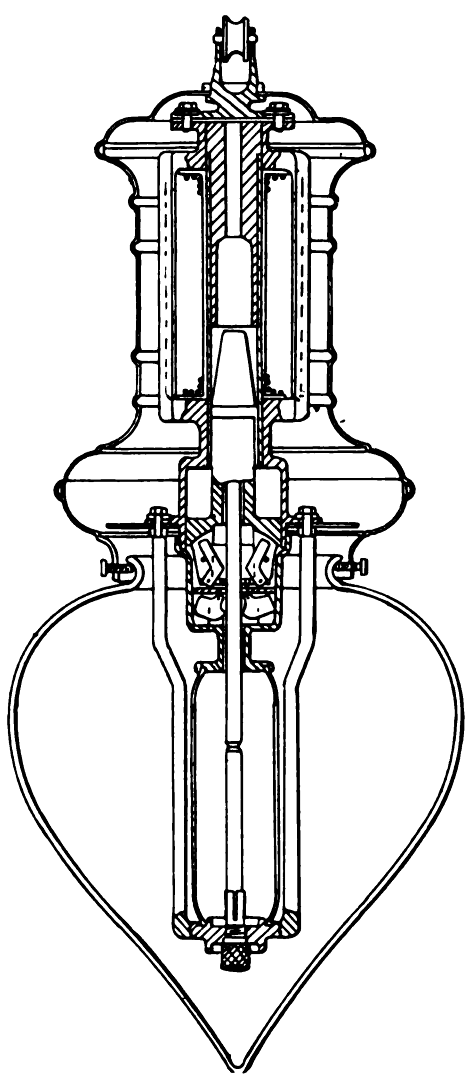

Fig. 130.—The "ARK" Lamp of Johnson & Phillips.

and the mechanism is again locked. In the lamps in which the carbons are separated when at rest, the same process goes on, the shunt magnet referred to above operating when it is sufficiently powerful to overcome the spring.

The feed mechanism, as mentioned, varies, and in Enclosed Arc lamps is very much simplified, some of them being able to dispense with the feed magnet altogether, the decreased current strength lessening the power of the main electro-magnet, and that being sufficient to cause a feed. The arc in the Enclosed Arc lamp is very much longer than that in the Open Arc lamp, and this, together with the fact of the much lower consumption of the carbons, allows of greater liberties being taken in the matter of the feed.

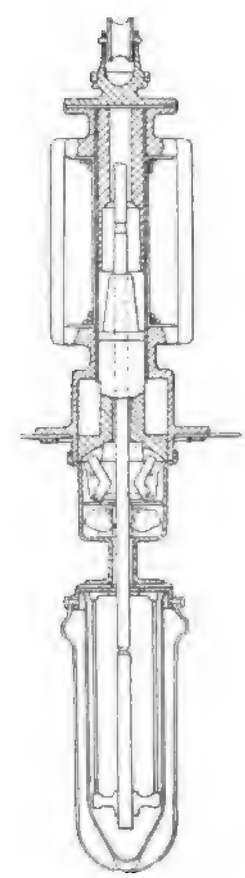

Fig. 131.—"ARK" Lamp with Parallel Outer Globe.

The great trouble in the matter of the feeding of arc lamps is, at every feed, a wink of greater or less duration and more or less perceptible takes place in the light. An arc lamp does not wink, or very rarely so, until it feeds, no matter how long the arc is. Hence with a long arc, a small feed very occasionally is quite sufficient. This would not be possible with Open Arcs, on account of the fact that a long arc with that type of lamp means very rapid consumption, and very frequent feeding. The Enclosed Arc also gives another advantage over the Open Arc; the longer arc allows the light furnished by the lamp to pass out much more freely, while the small arc necessary with the Open Arc confines it very much. On the other hand, the Enclosed Arc is usually much richer in violet rays than the Open Arc. Long arcs are nearly always richer in violet rays. The Open Arc will be from $\frac{1}{16}$ to $\frac{3}{32}$ inch long, where $\frac{1}{2}$ inch is quite common for Enclosed Arcs, and in special cases arcs as long as 1 inch have been burnt. The Enclosed Arc carbons burn for 100 to 150 hours, while 18 hours is

a very good performance for Open Arcs. Enclosed Arcs require specially prepared carbons.

Figs. 130 and 131 illustrate enclosed arc lamps by Messrs Johnson & Phillips, of Old Charlton. The arc is enclosed within a small glass cylinder which is practically air-tight, so that a set of carbons lasts about 100 hours. There is no upper carbon holder, the carbon being slipped into the lamp, and fed down automatically from time to time as it consumes away. The arc is struck and regulated by the solenoid, in the upper portion of the holder of which a few convolutions of the winding only are shown. This coil surrounds a casting which carries a fixed internal pole-piece at the upper end; the casting is enlarged below and carries a movable core, the latter being slotted at its lower part to provide space for four clutch cams, which are pivoted at their lower ends in a loose plate. When the core is raised the cams are forced inwards by their pins, causing them to grip the carbon, and carry it with them. When the core descends the grip of the cams is relaxed and the carbon slides through them. The current is fed into the upper carbon by four contact pieces which are lightly pressed against it by gravity. The lower carbon is fixed in a holder into which current is led by a conductor. The contact pieces automatically cut the lamp out of circuit when the carbons have burnt down to a certain point. Both figures contain the same essential mechanism, but Fig. 130 has an ornamental stamped casing, and pear-shaped globe, instead of the parallel round-ended outer glass of Fig. 131.

There is a new type of arc lamp that has not long been placed on the market, in which the carbon from which the rods are made is mixed with salts of sodium. The effect is the orange-coloured light that may be seen in London on the outside of some of the shops. The sodium arc has the peculiar property that if sufficient sodium is present, the light is nearly true sunlight, so far as matching the colours of fabrics is concerned, whereas nearly every other form of artificial light is rich in red rays, and therefore gives different colours with certain fabrics, by day, and by artificial light.

Arc of Action.—*See* **Arc of Contact.**

Arc of Approach.—That portion of the **Arc of Contact** of the teeth of wheels in mutual gear which begins in advance of, and terminates at the pitch point. The most severe friction occurs here.

Arc of Contact.—The entire length of arc on which the mutual contact of a pair of teeth in driver and driven, or driver and follower wheels takes place. It is also termed the path of contact, and the arc of action. The length of this arc is determined by the diameter of the generating circle,—the base circle in the cycloidal form of teeth.

In Fig. 132, the point of contact of the teeth traverses the path or arc of contact of the teeth from *b* to *d*, coinciding with the arcs of the

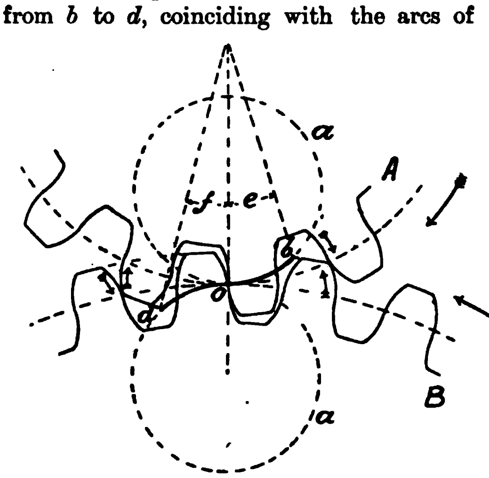

Fig. 132.—Illustrates Arcs of Contact, Approach, and Recess.

circles *a a*. *b o* is the arc of approach, *o d* the arc of recess. The angles cut off by *b o*, *o d* are the angle of approach *e*, and the angle of recess *f*.

In Fig. 132, wheel A driving B, and *a a* being the generating circles, the teeth first came into contact at *b*, and the sliding of the teeth over each other until the point of contact coincided with the pitch point *o* was, as indicated by the small arrows, producing severe friction of a pushing character. At *o* for an instant there is no friction, and then until *d* is reached the sliding friction becomes of a drawing kind, which is less severe than that of pushing. The difference between the two has been well likened to that of pushing a stick along on the ground in front of one, and that of dragging it behind.

Looking at the circles *a a*, it is clear that if their diameters were enlarged in wheels of the same pitch, the path of contact would be lengthened, and *vice versa*, which fact gives the patternmaker and gear designer a means of ensuring that one pair of teeth shall not leave contact until the next pair comes into engage-

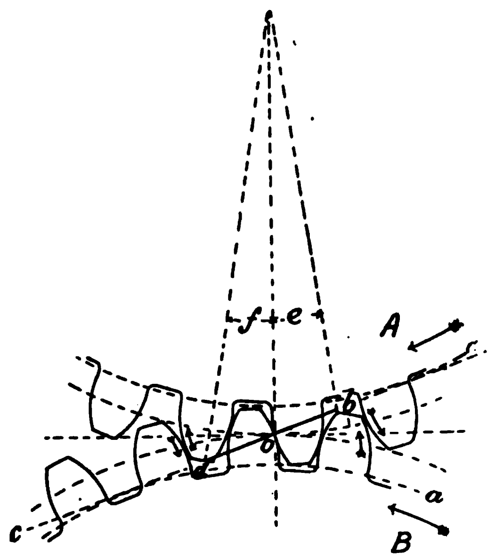

Fig. 133.—Illustrates Arcs of Contact, Approach, and Recess.

ment. A coarse pitch and a small generating circle should not be combined, otherwise the arc of contact will be so short that one pair of teeth will have quitted contact before the adjacent pair entered into engagement.

In involute teeth, the path of contact becomes a straight diagonal line which is a tangent to the base circles. The pitch of the teeth relatively to the lengths of the teeth faces or addenda must be considered in relation to the length of the tangent line. A high angle of obliquity in involute teeth, and a coarse pitch, give the same results as small generating circles and a coarse pitch in cycloidal teeth.

In Fig. 133, the path of contact extends from *b* to *d*, on the line tangent to the base circles *a a*, whence the teeth are developed. *b o* is the line of approach, *o d* that of recess, and *e*, *f* are the angles of approach and recess respectively.

Arc of Recess.—That portion of the **Arc of Contact** of the teeth of wheels in mutual gear which commences at the pitch point and terminates when the teeth cease their engagement. The friction is less severe here than it is along the arc of approach.

Arc Pitch.—The pitch of a toothed wheel measured round an arc of the pitch circle. It is well to insist on the necessity for its adoption, because wheel patterns are made in which measurement of a chord of the arc is taken. This difference can be altogether neglected in large wheels, but it leads to error in small pinions of coarse pitch, in which it is easy to get an error of $\frac{1}{16}$ inch in the pitching of the teeth. Fig. 134 illustrates this, in which segments of small and large circles are drawn. Here the true arc pitches extend round *o a b*, and *o a d*, but if chord pitches *c c* were taken they would be *o e*, *o e*. The result in the action of the teeth would be that the first condition of gearing would not be fulfilled, namely, that ideal wheels must gear, just as though they were rotated by the frictional contact of smooth cylinders. With unequal pitching as at *e e*, the motion of the true cylinders *a a* would be exchanged for a jerky movement as often as each successive pair of teeth came into gear, due to the difference in the lengths of the pitches. The patternmaker will sometimes, finding that the compasses set for the pitch of a wheel pattern will not pitch the pinion round, conclude

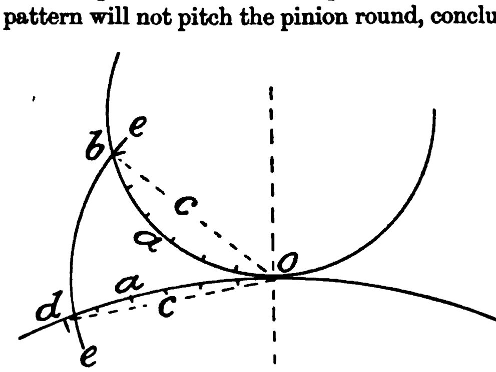

Fig. 134.—Arc, and Chord Pitch.

that the calculated diameters are wrong. Or, finding that only one tooth of a small pinion is in contact with the wheel teeth at one time, he will conclude that the pitch is not quite coarse enough.

The proper way to avoid this error is to

calculate pitch circles and pitches strictly on the basis of circumferences of the circles. The illustration also shows how practical accuracy can be obtained by subdividing and stepping round several smaller equal arcs to total to the larger dimensions. This last method is also often convenient in measuring round irregular curves in various kinds of work, and arcs of very large radius, which either cannot be calculated conveniently, or sometimes not at all.

Arc Welding.—*See* **Electric Welding.**

Area—C.G.S. Unit of.—The square centimetre,—the area of a square of one centimetre side.

Areas.—The calculation of areas is continually required in the various branches of engineering and in allied trades. The moulder, for example, has to estimate the quantity of metal necessary for any particular casting. Frequently it is impossible to find the cubic contents until the surface of an irregularly shaped pattern has been divided up into triangles, segments, &c., and their respective areas calculated. In the boiler shop, again, a knowledge of the methods of calculating areas is useful for estimating quantities of metal in plates, &c.

An important point to remember in the reckoning of areas, is that length, breadth, height, and all other dimensions must be of the same denomination. If one measurement is in feet, and another in inches, both must be stated in feet or inches, and fractions of feet or inches, before it is possible to perform any calculation of the area. Care must be taken also, to distinguish between "feet square" and "square feet." Thus, 5 feet square means 5 feet × 5 feet or 25 square feet, while the former expression means simply an area of 5 square feet.

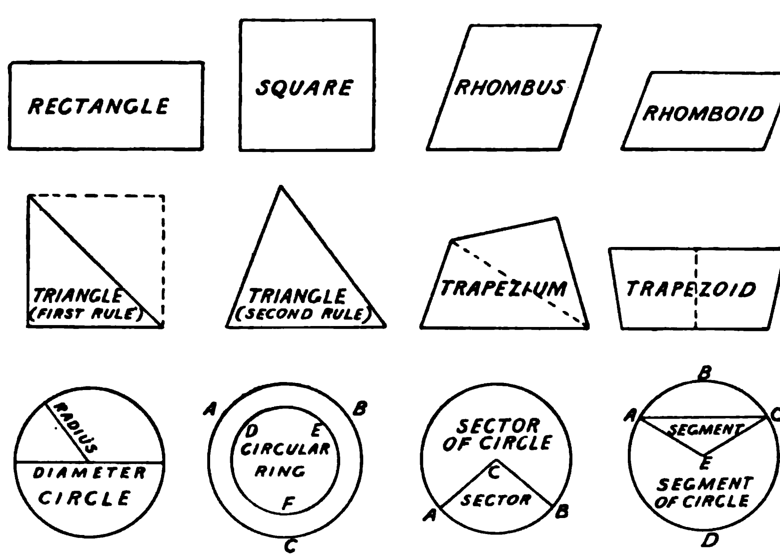

Fig. 135.—Areas.

Areas of Rectangular Figures, Fig. 135.—The *rectangle.* A rectangle is a four-sided figure having its opposite sides equal, and its four angles right angles. To find area, multiply the length by the breadth and the product will be the area. (Sometimes the terms base and height are used respectively for the length and breadth.)

The *square.* A square may be regarded as a rectangle of which the sides are all equal. Length and breadth being equal, the area is found by squaring the side.

Areas of Parallelograms.—A parallelogram is a figure in which the opposite sides are parallel. The rectangle and square are thus parallelograms, but the term is generally applied to figures in which the angles are not right angles, such as the rhombus and the rhomboid. The former is a figure whose

four sides are equal to one another, but none of its angles are right angles; the rhomboid has its opposite sides equal and its angles are not right angles. To find the area of either a *rhombus* or *rhomboid*, multiply the base by the perpendicular height. In the case of the rhombus, if the diagonals only are given, the area equals half the product of the diagonals.

AREAS OF TRIANGLES.—A *triangle* is obviously equal to half a rectangle having the same base and height. To find area, multiply the altitude by the base and take one half the product. (The altitude of a triangle is the line drawn from the vertical angle perpendicularly to the base.) The area may also be found if the lengths of the three sides of a triangle be given. From half the sum of the three sides, subtract each side separately; multiply the half sum and the three remainders together, and the square root of the product will be the area. This is more conveniently stated and easier remembered if put in the form of a formula. If the three sides of the triangle are represented by the letters a, b, and c respectively; let s stand for the semi-perimeter or half the sum of the three sides. Then the area will be:—

$$\text{Area} = \sqrt{s(s-a)(s-b)(s-c)}.$$

AREAS OF QUADRILATERALS.—The *trapezium* is a four-sided figure, none of whose sides are parallel. To find its area, divide the trapezium into two triangles by drawing a diagonal; calculate the area of each triangle and the sum of these areas equals the area of the figure.

The *trapezoid* is a four-sided figure of which only two of the opposite sides are parallel. Its area may be found by the above rule for trapeziums, but generally it is calculated by the following rule:—Multiply half the sum of the two parallel sides by the perpendicular distance between them.

AREA OF THE CIRCLE.—The area of the *circle* may be found by any of the following three methods:—

$$\text{Area} = \text{diameter} \times \cdot 7854.$$
$$\text{Area} = \text{radius} \times 3\tfrac{1}{7}.$$
$$\text{Area} = \tfrac{1}{2}\ \text{circumference} \times \tfrac{1}{2}\ \text{diameter}.$$

The area of a *circular ring* is found by calculating the area of each circle and subtracting the area of the inner circle from that of the outer circle.

The *sector of a circle* is the figure bounded by the arc of a circle and two radii. To find its area:—As 360° is to the number of degrees in the angle of the sector, so is the area of the circle to the area of the sector. Or, multiply the arc by the radius, and take half the product.

The *segment of a circle* is the figure bounded by the chord and the arc it cuts off. In the figure, ABC is the lesser segment and ADC is the greater segment. Evidently in the figure, the area of the segment ABC equals the area of the sector AECB minus the area of the triangle AEC. Hence the rule:—Find the area of the sector which has the same arc, and then subtract the area of the triangle included between the radii and the chord of the segment. Or, if the chord of the arc and the height be given, add to one-fourth of the square of the chord two-fifths the square of the height, and multiply the square root of the sum by four-thirds of the height. This gives the area of the segment approximately.

Argillaceous Iron Ore.—Iron ore in combination with clay, described under the better known term **Clay Band.**

Arithmetic naturally enters largely into engineering practice, and a sound knowledge of the various rules is a valuable asset to the craftsman in whatever shop his work may lie. Strange as it may appear, it is nevertheless a fact, that the most involved and complicated processes are merely complex examples of the four elementary operations of addition, subtraction, multiplication, and division. Ability to perform these four operations with absolute accuracy is therefore thoroughly essential. After that it is merely a question of grasping and remembering methods of applying them. It goes without saying that the multiplication tables should be thoroughly known.

Certain rules of arithmetic repeatedly occur in the workshops, fractions being used largely in screw cutting and in milling spirals; the calculation of ratios enters into screw cutting; square, and cubic measure, areas and volumes, and decimal fractions are useful in all cases. On the other hand, the engineer requires little or no knowledge of stocks, exchange, present worth, interest, &c. In this work, therefore,

only those rules will be dealt with which are likely to prove of value in engineering practice.

The different rules are dealt with under:—Arithmetical Mean, Arithmetical Signs, Cube Root, Decimal Fractions, Fractions, Greatest Common Measure, Least Common Multiple, Percentages, Proportion, Rule of Three, Square Root, &c.

Arithmetical Mean. — An arithmetical mean is a number exactly intermediate between two others. The arithmetical mean between 9 and 13 is 11, for $9+2=11$, and $11+2=13$. The rule for finding this mean is to add the two numbers together and take half their sum.

Arithmetical Progression.—A series of numbers that increase or decrease by a common difference. 1, 5, 9, 13, 17, is an ascending series; 7, $5\frac{1}{2}$, 4, $2\frac{1}{2}$, 1, is a descending series. From one or more of the following formulæ it is possible to find the first term, the last term, the number of terms, the common difference, or the sum of the terms of any series of numbers in arithmetical progression.

$$s=\frac{n}{2}(l+a) \quad . \quad . \quad . \quad . \quad 1$$

$$l=a+(n-1)b \quad . \quad . \quad . \quad 2$$

$$s=\frac{n}{2}\{2a+(n-1)b\} \quad . \quad . \quad 3$$

in which a denotes the first term, l the last term, b the common difference, n the number of terms, and s the sum of the terms. For example, suppose it is required to find the sum of the series, 2, 4, 6 . . . to 50 terms. Taking the third formula:—

$$s=\frac{n}{2}\{2a+(n-1)b\}$$

put 50 for n – the number of terms, 2 for a – the first term, and 2 for b – the common difference between the terms of the series. Thus we get:—

$$s=\frac{50}{2}\{2\times 2+(50-1)2\}=$$

$$s=25\{4+49\times 2\}=$$

$$s=25\{4+98\}=$$

$$s=2550.$$

Arithmetical Signs.—These are identical with **Algebraical Signs**, to which may be added the following. The decimal point, . separates whole numbers and fractions. Thus $129{\cdot}528=100+20+9+\frac{5}{10}+\frac{2}{100}+\frac{8}{1000}$. : :: : are the signs placed between four proportional numbers, as 5 : 6 :: 10 : 12, which is commonly read "5 are to 6 as 10 are to 12."

Arm.—A term which is loosely applied to many portions in the shops, *e.g.* the arms of wheels, and pulleys, lever arms, the arm of a machine, as of a drilling or milling machine, the arm of a bracket, of a John Bull, of a holdfast, of a cramp, and others.

Armature.—*See* **Dynamo**, and **Motor—Electric**.

Armoured Cables, or **Armoured Leads**.—Electric conductors are protected with a covering, where there is risk of damage occurring. Lead is the most common form of armour, frequently supplemented with other materials. A typical method of treating cables which have to lay direct in the ground is as follows:—On a tinned copper conductor, rubber is first placed for insulation, then taped, covered with lead, yarned with tarred jute, armoured with two laps of steel tape, jute yarned, and served with waterproof composition. *See also* **Electric Cables**.

Armoured Concrete.—Armoured concrete, or reinforced concrete, as it is sometimes more appropriately called, is concrete in which a suitable steel framework is embedded, to enable the concrete to withstand tensile and shearing stresses. In this combination we have a practically new material of enormous strength and durability. It is not only commercially cheaper, but is superior in every way to either of its two constituents alone. It is superior to steel, because concrete not only prevents steel from rusting, but checks the extension of rust when it already exists. If oxide of iron is present, it becomes deoxidised. The hardness of the concrete, and its grip on the steel, is inclined to increase with age. For building purposes, therefore, armoured concrete is the strongest and most durable material obtainable. It is safer than bare structural iron or steel work in the case of a fire. When subjected to intense heat, the unprotected metal bends and falls, but concrete is not injured either by extremes of heat or cold. The adherence of concrete to embedded metal is satisfactory. It is a very simple matter to make the metal of such form that it cannot possibly pull out, but the coefficient of adherence

per square inch of surface in contact is reckoned to be about 600 lb., so that breakage is likely to occur long before slipping. It is this rigid adherence and the equality of expansion of the two materials, which is also well established, that makes the combination so satisfactory.

Without steel reinforcement, concrete cannot resist much tensile or shearing stress, though it stands compressive forces very well. In a horizontal beam, or in a floor, the upper surface is in compression, and the lower is in tension. The tendency is for the under surface to crack open, and the beam or floor to sink in the middle, until the compressive strength is overcome, and the crack results in a break entirely through. The steel in such cases is not put half-way between the upper and lower surfaces, but in the latter area, where its tensile strength is most required. Similarly, in all armoured concrete constructions the steel is placed where the tensile strain will be greatest, and in calculating the strength in those parts, the tensile value of the steel is reckoned, and the concrete not considered. The introduction of steel reinforcement not only effects an immense saving in thickness of concrete (*see* Fig. 136), but the combination possesses the properties of both materials. Concrete alone always breaks before any appreciable deflection is observed. Armoured concrete possesses more elasticity, and deflects considerably before breaking.

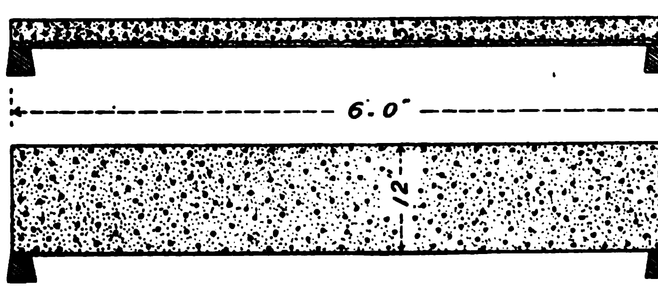

Fig. 136.—Illustrates Relative Thickness of Concrete Slab, with and without Reinforcement.

There is no doubt that with armoured concrete buildings can be constructed that are practically imperishable. They are fire-resisting, and they withstand better than any other material the wear and decay of time. A building of armoured concrete is one monolithic mass without joints, and of material more durable than the best natural stone. From the time of the Roman Empire till almost the middle of the nineteenth century the general use of concrete fell into abeyance, but there is no doubt that as made at the present time it is equal to the concrete of antiquity. But we had been using our Portland cement concrete for a long time before the advantage of encasing metal members in it was perceived. It was in France that experiments in this direction were first made, and England was slow in recognising its merits.

As it is necessary that the steel should be judiciously distributed within the concrete, and as this has to be done on the spot where the structure is being erected, a definite and simple system is desirable, so that the work can be done if necessary by men with comparatively little training. Endeavours have therefore been made to devise systems whereby the steel shall be placed precisely where it is required, in order to obtain the maximum strength in a floor, or beam, or arch, or column. A simple and satisfactory method for slabs of concrete is to encase a sheet of steel lattice, or mesh-work—expanded steel—in the slab. This holds together and strengthens the entire slab. Metal expanded in this way was already manufactured and used for fencing before the idea of using it in concrete occurred. It is expanded by cutting slits in a solid sheet and stretching it out until a trellis of diamond-shaped meshes is formed. *See* **Expanded Metal**. With a comparatively small amount of steel a slab of concrete can thus be reinforced throughout. Another important advantage in the use of sheets of metal expanded in this way is that when a sheet of it is laid on a flat surface only one point of each mesh touches the surface. This enables the concrete to get entirely beneath it without difficulty, and leaves the metal encased as close to the under surface of the slab as possible. This, as we have already said, is just the place where the metal is required. The laying of a concrete floor reinforced with expanded metal, therefore, is not very much more

troublesome than laying one without the metal. Care has to be taken to see that the concrete is well tamped down around and beneath the meshes. The long way of the mesh is best capable of resisting tensile strain, and so the metal is laid with this direction of the mesh in the shortest way of the span. Thus, presuming the floor slab or bay is 10 feet span from centre to centre of bearings by 200 feet the other way, the long way of the mesh should run in the 10 feet direction. This is a most important point in the system of construction, since if the metal is laid in the other direction its efficiency is decreased by 50 per cent. Where joints have to be made in the metal, a lap of one mesh is sufficient to give the same strength as a sheet without a joint. In building walls it is necessary to have round or flat steel bars at intervals, to which the fabric of expanded metal is attached.

In armoured concrete, expanded metal is suitable primarily for slab-work, such as floors and walls. This, indeed, is often all that it is desired to use concrete for, as it is generally cheaper to use steel or iron alone for beams and supports. But when a structure is entirely of armoured concrete, the beams and supports can be reinforced better by steel rods and bonds suitably arranged than by sheets of expanded metal. A beam is subjected to stresses that it can be fortified against more effectively by the use of rods than by a strip of expanded metal along its under part, or by expanded metal arranged in any other way within it. Similarly a column, which under great pressure has a tendency to develop vertical cracks and burst outwards, can be strengthened better by vertical rods enclosed by rings at intervals than it could be by the use of expanded metal. The hold of the concrete on the metal is so secure, that provided the steel is arranged to take the stresses which the concrete is least adapted for, it is of no practical importance whether the metal consists of a number of members or of one homogeneous piece. Pieces of metal of sufficiently large section to almost divide the concrete into blocks, of course, are objectionable and quite unnecessary. In the case of slabs of concrete, expanded metal imparts a degree of elasticity to the slab which concrete alone is incapable of until it is united with steel. The elasticity of the combination is something between that of steel alone and concrete alone. The difference between the two materials in this respect is very great, but when combined, the adhesion is so strong that the concrete loses some of its brittleness, and under tension will even stretch with the steel to a considerable extent before breakage takes place. The steel in its turn is greatly stiffened by the concrete, and this combined with the monolithic character of all the parts of an armoured concrete structure, makes it less subject to vibration than a building of any of the other usual materials. This absence of vibration has been noticed in factories built of armoured concrete where heavy machinery is running. Another peculiarity of a structure built entirely of armoured concrete is that damage to one part does not necessarily result in the collapse of parts contiguous to it. This is because the structure is practically as if it was cut from a solid mass of material, without joints, and without any part being entirely dependent on another for support.

An armoured concrete building may be considered absolutely fire-resisting. It has passed successfully through some severe tests in accidental fires, and it has been still more severely tested for the purpose of finding out whether it was possible to injure it by fire and applications of cold water.

Armoured concrete is also often used to protect the girders and columns of a building from distortion through fire. This is usually done by wrapping expanded metal round them, and covering this with concrete in the same way that a lathed ceiling or wall is plastered. A covering of armoured concrete in this way readily lends itself at the same time to the formation of mouldings and ornamentation wherever desired.

Armoured concrete is employed for a great number of purposes, and no doubt new uses for it will be found as it becomes better known and more commonly adopted. It has been employed advantageously for all purposes for which brick and stone have hitherto been used. In bridges and similar structures that are frequently made of bare steel, armoured concrete is superior because it is more durable and more

rigid. The material itself is not more expensive than steel, but a bridge of armoured concrete generally costs more than a steel one, because the temporary wood centring necessary for concrete is an expensive item. It is, of course, stronger, and more permanent than a structure in which wood beams and joists are used, and especially is expanded metal better than wood laths for binding concrete or plaster as used on ceilings and walls. Armoured concrete is an excellent material for buildings of all kinds, and for all parts of a building from the foundation to roof. It is especially suitable also for irregular and unusual shapes, such as domes and other purely ornamental forms. For a given degree of strength its weight is less than other materials. It is used also for piers, docks, fortifications, conduits, reservoirs, retaining walls, lighthouses, and other structures.

The methods of construction vary according to circumstances, but the principle is always the same. The steel is inserted in the right place, and in sufficient quantity to withstand the tensile stress. As near as can be calculated, the concrete and steel are so proportioned and arranged that when tested to destruction the concrete will yield in compression, and the steel in tension simultaneously.

In floors with expanded steel in the lower face of the concrete the relative proportion of metal to obtain the best results is about ½ per cent. as compared with the sectional area of the slab.

The best type of armoured concrete floor for carrying heavy weights is the channel arch floor, Fig. 137. This consists of a series of girders spanned first by arches of channel iron, the amount of arching being about 1 inch per foot of span. The highest points of the arches may be on the same level as the top faces of the transverse girders, and the sheets of expanded metal are laid flat across this level. It is not, however, necessary that they should be at this level, as sometimes the transverse girders are considerably lower than the highest point of the arches, in which event concrete is filled in on top of the girders to the under side of the floor level. This is often done for purposes of economy. Before the metal is laid, temporary wood centring as shown has to be fitted between, and flush with the tops of the girders, and pieces are fitted on each side of the channel iron arches, so that the channels can be filled with concrete,

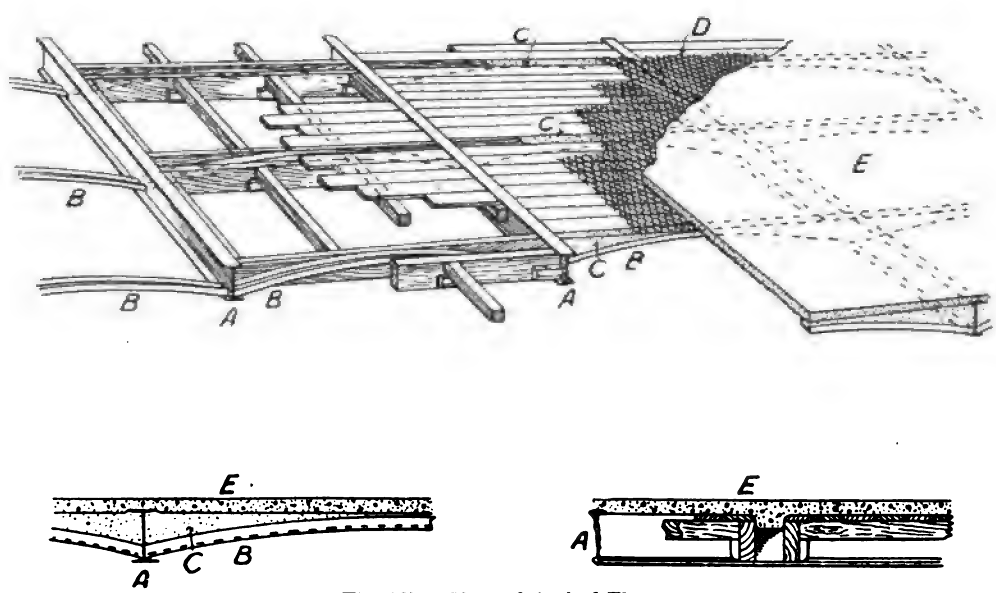

Fig. 137.—Channel Arched Floor.

A. **Rolled steel floor channels.** *B*. **Arched steel channels.** *C*. **Concrete filling over arched channels.** *D*. **Expanded metal tension bond.** *E*. **Finished concrete floor.**

which in the middle at the highest point of the arch, fills the channel up above the level of its flanges, giving at least as much concrete in depth at the crown of the arch as in the thickness of the flooring slab, or decking, and of

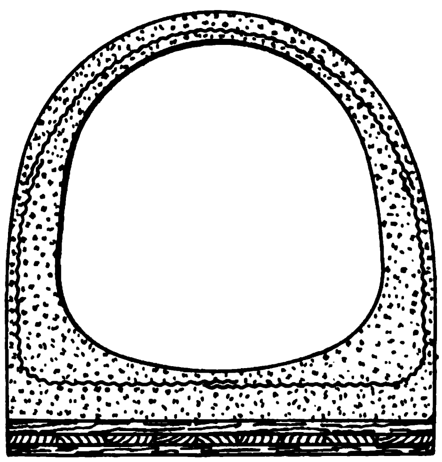

Fig. 138.—Section of Sewer Built of Armoured Concrete.

the same width as the channel iron. This makes the strongest possible skeleton on which to lay the slab floor. At this stage the level surface consists of the girder flanges, the concrete above the channel arches, and the wood centring fitted between these. As the centring has to be withdrawn after the concrete is set, its surface is covered with oiled paper, or washed with soap water, or lime-whited, to prevent the concrete from adhering to it. The sheets of expanded metal are laid on this surface, slightly overlapping each other at the edges, and where possible, with the edges lying on the supports. If the slab is to be thin and the metal does not lie flat, it is held down to the centring where necessary by nails, the ends of which can afterwards be cut, or clipped off. When the expanded metal has been adjusted in position, the concrete is put on it and tamped down into the meshes. This entirely embeds the metal in the lower surface of the concrete. It is necessary that the metal should be completely embedded in order to protect it and to leave a smooth under-surface of concrete. The best position for the metal is therefore about $\frac{1}{2}$ in. within the surface. This is the location the metal naturally assumes when the concrete has been properly worked into the meshes. It should never be painted or have anything applied to its surface before insertion in concrete, because concrete itself is the best protection, and adheres best to the bare metal.

Armoured concrete for foundations is both cheaper and better than concrete alone. A large sheet of the latter will often crack if the ground below it subsides unequally. A sheet of armoured concrete of no greater sustaining power would slightly deflect instead of breaking. It is also used in the construction of sewers, Figs. 138, 139.

In walls, and in the partitions of tanks, bins, and bunkers, where pressure may occur on either side of the slab, the concrete is generally reinforced on both sides. The building of vertical slab-work in armoured concrete involves more work than horizontal slabs. In vertical work temporary centring on both sides is usually employed. Sometimes the metal is laced to supports, and sometimes, where two sheets of expanded metal are used, as in the cases just mentioned, they are dropped between the centring and kept apart by vertical strips of wood while the concrete is put in and rammed. Sheets of metal that meet at right angles are connected to each other at intervals by dogs of

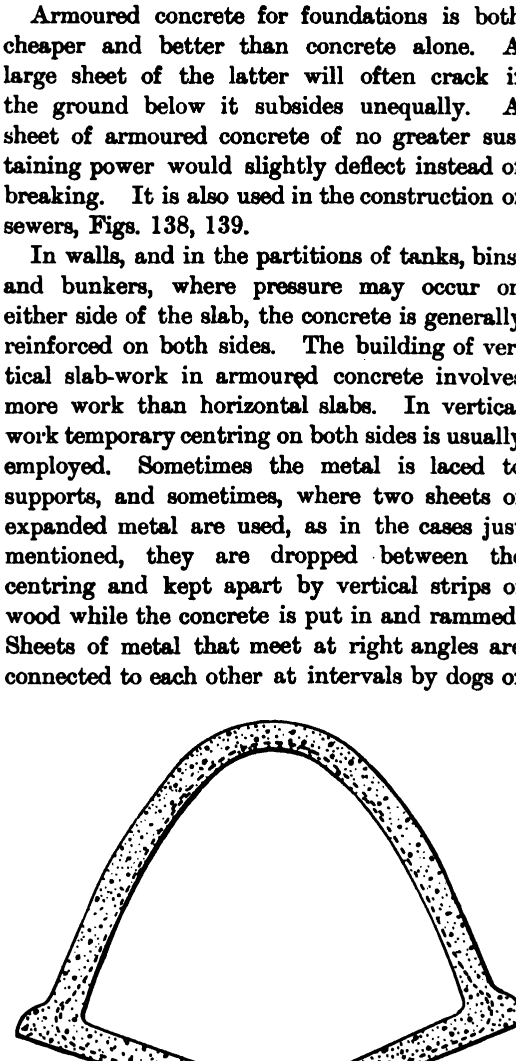

Fig. 139.—Section of Sewer in Armoured Concrete.

$\frac{1}{4}$ in. round iron. In this class of work the $\frac{1}{4}$ in. iron dogs are pitched at 18 in. centres. They act as distance pieces, and keep the two sheets of metal at the correct distance apart, so that there is room for the concrete to be rammed

through the meshes of the metal, and against the temporary centring, to entirely embed the expanded steel, the latter being about half an inch from each face to the wall. In addition to this, strips of expanded metal 3 or 4 feet long are laid flatwise through parts where walls and partitions cross each other. These strips are placed at intervals of about a foot in height, and go alternately at right angles to each other through the crossing. This is the method adopted by The New Expanded Metal Co., Ltd., London.

In structural work where expanded metal is not used, systems of rods and connections are employed. This, as already said, is specially suitable for the skeleton work of a building, such as beams and columns. Hennebique's Ferro-Concrete is a system of this class. A beam, instead of being of bare steel bolted, or otherwise attached to its supports, is made with steel and concrete in the most economical proportions, and with the steel disposed in the correct positions for withstanding the stresses the beam will be subjected to. This not only makes a light and strong beam, but the beam and the parts connected to it form one solid, monolithic mass.

The Hennebique beam is built with longitudinal round steel rods in its lower part where the tension is greatest, and with a series of flat steel stirrups arranged vertically in the beam with their lower ends hooked round the horizontal rods. These stirrups correspond to the web in an ordinary rolled steel joist. They are placed closer together near the ends of the beam where the shearing stress is greatest than they are in the middle portion. Their upper ends are hooked so that no amount of stress on the lower rods could cause them to pull through the concrete. In addition to the tension rods in the lower part of the beam there is a further arrangement of such rods raised from the lower part to the upper (*see* Fig. 140). This is calculated to fortify the beam against the tensile stresses which are greatest in the centre of the lower side, and in the upper side near the supports. Between these two points the line of stress crosses at an angle. The rods are bent to follow this angle. In the middle of the beam the rods lie close to the lower surface for a short distance. Then they incline up to the upper surface and follow that, and finally the end of the rod is spread

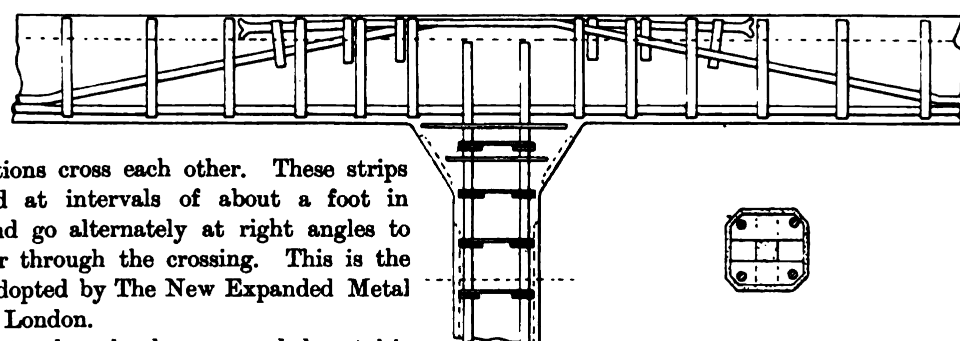

Fig. 140.—Pillar and Beam in Ferro-Concrete.

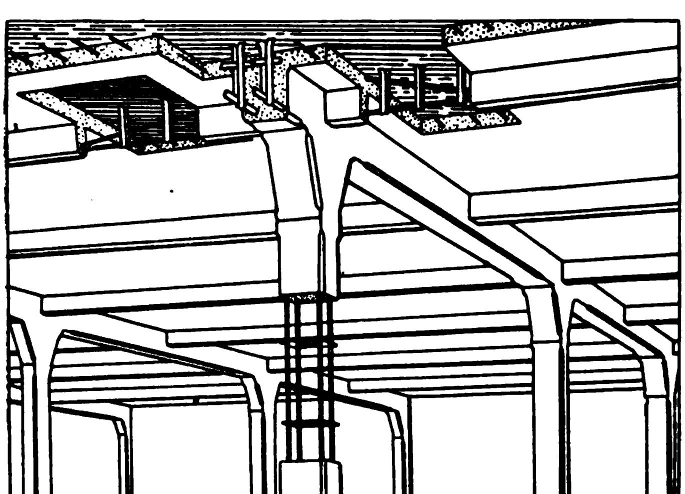

Fig. 141.—Pillars, Beams, and Floor in Ferro-Concrete.

open. The upper surface of the beam is really at the same time the upper surface of the floor, for they are made in one, and the floor is considered as a very wide and shallow beam, and is reinforced in precisely the same way as the beam. Piles are built in ferro-concrete. *See* **Piles**. Other specific examples of work in armoured, and ferro-concrete will occur in these volumes.

Armoured Hose.—Hose is armoured for two principal reasons, — to protect it from damage, and to prevent it from becoming distorted and injured by kinking, collapsing or twisting. The first-named occurrence is likely to happen to ordinary hose, either through persons treading upon it, objects striking, or pressing against it, or through the hose being dragged over rough ground, &c.; the second by the bending and contortion which is unavoidable in a flexible hose, used in all sorts of awkward situations. The armour must be sufficiently rigid to resist any of these damaging forces without giving way, while still permitting enough flexibility. The most approved method of protection is that of cast-steel wire, coiled spirally around the hose, thus providing a strong and durable covering, without sacrificing the capacity of the tubing for bending.

A clip is employed to retain the wire at the ends of the hose. Fig. 142 shows a special coupling designed by F. Reddaway & Co., Ltd., for their armoured hose, which grips the ends of the hose, including a few turns of the armour. The screwing up of the outermost nut jams the coupling around the hose tightly. To unite the two coupling ends, the union nut seen in the centre is employed, which permits of rapid attachment and detachment.

The uses of armoured hose comprise those for hydraulic service, for cranes, riveters and other tools, for which the Reddaway hose is made to stand pressures up to 10,000 lb. per square inch; for pneumatic work, driving drills, riveters, and all classes of air tools and machines. In both of these cases flexibility is of great importance, and the dragging about and rough usage of the hose renders armouring imperative. Many gases and liquids are also conveyed by this hose, including steam, and boiling liquids. For steam at high pressures, up to 200 lb., an asbestos lining is employed. Armoured hose is made up to about 6 inches in diameter.

Armoured Turret.—Applies to guns which are protected with armour to prevent risk of their being put out of action. It includes the turret proper and the cupola, movable vertically in the fittings of disappearing guns. In fixed guns the cupola rotates with the gun.

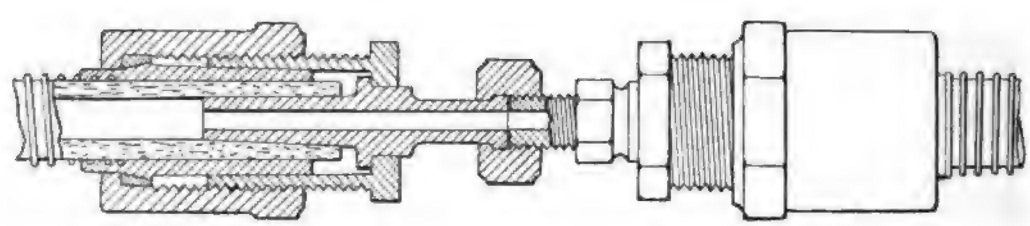

Fig. 142.—High-Pressure Coupling for Armoured Hose.

Armour-piercing Projectiles.—*See* **Projectiles**.

Armour Plate.—The Parkgate Iron Works of Rotherham appears to have rolled the first armour plates in England. This firm supplied 2,000 tons of plates, ranging from 3 to 4½ inches thick, for H.M.S. *Terror*, which was invulnerable to any gun then in existence. The French armoured ship *La Gloire* (1859), built of wood and faced with iron, had preceded the *Terror*, and formed with her sister vessels the first armoured battleships afloat, or as they were termed then, and for many years subsequently, "Ironclads." Previous to this, armour had been used in the Crimean War on floating batteries.

Numerous British wooden ships were hastily converted then. But the first notable British armour-plated battleship was the *Warrior* (1860), built of iron, and faced with wrought-iron plates. The last wrought-iron armour fitted to

Fig. 143.—Steel Armour Plate.
(Messrs Vickers, Sons, & Maxim, Ltd.)

Fig. 144.—Steel Armour Plate.
(Sir W. G. Armstrong, Whitworth, & Co., Ltd.)

Fig. 146.—Armour-Plate Rolling Mill. (Sir W. G. Armstrong, Whitworth, & Co., Ltd.)

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a German battleship in 1880, had a thickness of 12 inches.

Steel armour plating was introduced subsequently, but for a long time plates of this material were very unsatisfactory, for the same reasons that steel boiler plates were distrusted, namely, their brittleness, and want of physical uniformity. The first great advance was made with the invention of the compound plates on the Wilson system, that is, plates of wrought iron faced with steel. The molten steel was poured on the wrought-iron backing—raised to a white heat — and the latter prevented the plates from being smashed into fragments by projectiles. This class of armour plate was introduced about 1878, and was retained from 1880 to about 1892. Cast-iron projectiles were employed at this period, hardness being imparted by chilling them by the Palliser, and other processes, and the compound plates resisted the impact of these chilled shells, which became crushed against the plates. The weak feature of the compound plates consisted in the liability of the steel facing to flake off from its own backing.

In 1890, the superiority of plates of nickel steel over compound plates was demonstrated by trials in the United States. These plates owe their value to the addition of a small percentage of nickel to the steel. In 1890, Schneider was producing such plates. In the same year the United States Government made some important comparative tests at their Annapolis proving ground. Three plates were taken, a compound plate by Cammell & Co., a plain steel plate, and a nickel steel plate by Schneider, all three being supported by 36 inches of oak backing. The compound plate was perforated by all the different projectiles directed against it, the plain steel plate resisted perforation by them all, but was badly cracked by an 8-inch shot. The nickel steel plate not only kept them all out, but remained uncracked also. The result was the adoption of nickel steel by the United States for the armour of their battleships. Nickel steel armour plate was not adopted for the British Navy until 1896.

In 1889, the late H. A. Harvey, President of the Harvey Steel Co. of Newark, N.J., attempted the surface hardening which goes by his name, and one of his plates was tested at the Annapolis proving ground in 1890. Another and larger plate was tested in 1891, and others later, the tests of which showed greater resistance to penetration, and less of cracking than the compound plate. In these "Harveyised" plates, an intensely hard degree of carbonisation—"super-carbonisation" of the surface of nickel steel plates was produced by maintaining them in contact with carbon at a high temperature for several days. Then the faces were finally water-hardened. The plates were first enclosed in a mass of non-carbonaceous material, such as sand, on one side, and a mass of granular carbonaceous material, as charcoal, on the other side, and all were enclosed in a fire-brick compartment in the heating chamber of a furnace. Here the heat was maintained for a period ranging from five to twenty-seven days, at a temperature above the melting point of cast iron. Being then removed, the plates were allowed to cool down to a dull cherry red, after which the carbonaceous material was removed, and the surface chilled by immersion in cold water, or by the spraying of cold water upon it. The super-carbonisation can be performed in less time by the substitution of hydrocarbon gas for the charcoal, and this method formed the subject of several patents in the United States.

It was found, however, that the carbonisation produced a crystalline condition in the plates, to correct which they were subjected to compression while heated to a temperature below 2,000° Fahr. They were subsequently annealed, machined, and finally tempered with jets of water, after reheating to about 1,350° Fahr. These Harveyised plates successfully resisted the projectiles of a few years since, but have been displaced by the Krupp plates, hardened by a process which is a modification of the Harveyising methods. In these, the hardness is carried to a certain depth, leaving the backing very tough. The result is that the projectiles become broken, while the plates remain uncracked.

In June 1892 the first nickel steel plate made in this country was submitted for test by Messrs Vickers, of Sheffield.

In 1892 Krupp was producing the unhardened

plates of nickel steel, which displaced the compound plates, being found superior to them in every respect. In the following year, hardened nickel steel plates were introduced by this firm. The relative strengths were as follows:—Compared with wrought-iron plates, compound plates had a power of resistance equal to wrought-iron of 1·4 times the thickness, those of unhardened nickel steel equal to 1·6 times, and hardened nickel steel equal to 1·72 times the thickness. In 1895, the hardening was so graded that the resistance was raised to the equivalent of a wrought-iron plate of three times the thickness. These are the famous Krupp plates now manufactured under license by various armour-making firms in the world. *See* Figs. 143, 144. Fig. 144, Plate IX., shows a 360 lb. Krupp-cemented armour plate after the firing trial. It was selected from the plates forming the belt armour of the Japanese battleship *Kashima*, being built at the time of writing at Elswick Shipyard, and is a sample plate of the very latest K.C. armour being manufactured by Messrs Armstrong, Whitworth. It was tested at Ridsdale, December 1904, by firing four projectiles at it from a 9·2 gun, and the plate withstood a total striking energy of 36,918 foot tons, and was satisfactory in every respect.

The Krupp plates came into prominence as the result of a test made of an 11·8-inch plate at the firm's proving ground at Meppen in 1895. In these the alloy used is referred to as nickel-chrome. The super-carbonisation is carried on by means either of a hydrocarbon gas, or of solid carbonising materials. Vickers, Sons, & Maxim made their first Krupp plate in 1897, and the Carnegie Steel Co. their first in 1898, followed in the same year by the Bethlehem Steel Co. These plates are manufactured under the Krupp patent in England, France, the United States, Russia, and Austria.

The Krupp plates are chilled more deeply than the Harveyised plates, and they are less liable to crack. It has been claimed that their power of resistance is 20 per cent. greater than that of the latter, hence the reason for their employment by the European and United States Navies. Their superiority is more apparent in the case of the thicker than of the thinner plates, which is the reason why the recent American battleships have Krupp plates for all armour over 5 inches in thickness.

The development of armour plates has been hastened by the chrome-steel projectiles, oil, or water-hardened, which were introduced about 1896. These frequently penetrated the older plates without damage to the projectiles, so that inventors had to set their wits to work to produce the harder Harveyised, and Krupp plates. The invention of the soft-capped projectile prevents the breaking up of the shell and favours better penetration. Just how it produces this effect is not understood satisfactorily. It has been suggested as an explanation that the soft cap, by affording protection to the hard shell, gives an appreciable time for the latter to do its work, in reaching a softer zone of metal. Experiments have proved that the penetration is greatly increased by the fitting of the soft cap, even though the shell should ultimately fracture. The exceptions occur when the projectiles do not strike the armour in a normal direction, but at a considerable angle.

As wrought iron was the first kind of armour plate to be applied to ships of war, estimates of the piercing value of projectiles are stated as the thickness of wrought iron they will penetrate. There is good reason for this, due to the fact that wrought iron is of fairly uniform character, while steel is not. Steel may be as soft as wrought iron, or as hard as glass, and between these two extremes all degrees of hardness exist. So that to say that a projectile would pierce so many inches of steel tells nothing, unless the exact grade of steel were specified. But to say that it will pierce so many inches of wrought iron conveys a definite and well understood meaning.

A rule for testing an armour plate is that a projectile will pass through as many inches of wrought iron for each thousand feet per second of striking velocity as it is inches in calibre. Thus, a 6-inch projectile, having a striking velocity of 1,000 feet per second, will just perforate 6 inches of wrought iron. With a striking velocity of 2,000 feet per second it will just perforate 12 inches of wrought iron. Thus a standard is afforded for comparison with plates of steel.

Fig. 147.—Bending 8-inch Nickel Steel Turret Armour in 7,000-ton Press.
(Bethlehem Steel Works.)

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The weakness of wrought iron, or the enormous penetrating power of the modern projectiles, put it in either way, may be estimated by the following figures:—6-inch Krupp armour is equal to from 15 to 18 inches thickness of wrought iron. This is impenetrable to the shot from a 6-inch gun at moderate ranges. The Vickers' 6-inch gun has a penetration at the muzzle of 23·65 inches for the 45 calibre, and 26·9 inches for the 50 calibre gun. The Vickers' 7·5-inch gun has a penetration of 29·5 inches for the 45 calibre, and 31·8 inches for the 50 calibre gun. The Vickers' 12-inch gun of 45 calibre has a penetration of 51·9 inches at the muzzle. All the above applies to wrought iron. The Armstrong 12-inch guns have a penetration of wrought iron at the muzzle of 50·9 inches in the case of the 50 calibre. Such figures are almost inconceivable to the lay mind.

Perhaps the largest armour plate ever rolled is that which stood in front of the Krupp Hall at the Düsseldorf Exhibition of 1903. It weighed 104 tons, and measured 43 ft. 2 in. in length, by 11 ft. 2 in. in breadth, by 11¾ in. in thickness.

The total cost of armour plate per ton is about £80. This seems a big sum, but the plant is costly, the orders fluctuating, and the chances of plant being displaced by better methods are very great.

Armour plates are rolled from cast ingots which often weigh as much as 70 tons or more, to which about 25 per cent. is added for ingates, necessary to ensure soundness. The next operation is reheating in a furnace for 18 to 24 hours preparatory to slabbing under an hydraulic press. The presses used range in power from 3,000 or 4,000 to 14,000 tons power. An ingot is squeezed in the 8,000-ton press at Messrs Vickers' Works, from its thickness of 4 ft. 3 in., as cast, down to 14 in. thick, in about an hour. After a plate is slabbed, it is reheated and rolled, the sizes often being from about 26 to 28 feet long, by about 10 feet wide. The rolls at this works are made of steel forgings 3 feet in diameter, and 12 feet long, and all the details of the machine are on a similar massive scale. Plates are sometimes rolled down from a thickness of 29 in. to 6 in. at one heat. Plates which have to be bent are placed on an anvil under the press, and receive their curvature from a hollow mould attached to the crosshead.

The plates are planed subsequently, many edges being bevelled, some bolt holes are drilled, the faces hardened, and the edges then corrected by grinding, since their hardness precludes the possibility of bringing cutting tools into operation upon them. The drilling of such bolt holes as are required in the faces of the plates is done before hardening. As these occur at different angles, portable drills, rope, or electric driven, are used, and the tapping done. These are then plugged with clay to protect them from injury during the subsequent final chilling of the plates, as this hardening produced by super-carbonising extends to a depth of from 1 to 1½ inches. Subsequent correction of the edges is done by a grinder having a swivelling head, so avoiding the necessity for adjustment of the plates. Finally the bolt holes for the attachment of the armour plates to the hull are drilled from the back. These are undercut at the bottom for allowing air space, *see* Fig. 145, and clearance for the tap, and usually go to a

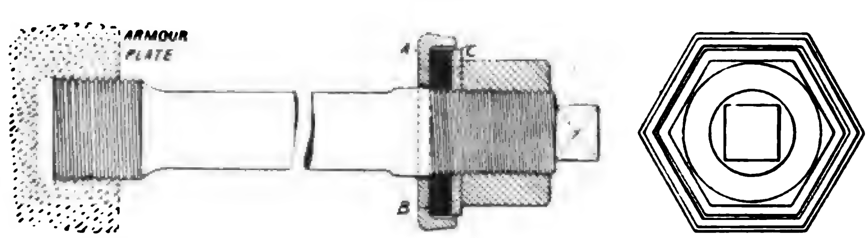

Fig. 145.—Armour-Plate Bolt. (Vickers, Sons, & Maxim, Ltd.)
A. Cup washer. *B.* Indiarubber washer. *C.* Plate washer.

depth equal to the diameter. A special bolt-hole drilling machine is used for this, having spindles with swivel movements in two directions, at right angles.

Armour-Plate Bolt.—*See* preceding paragraph.

Armour-Plate Grinding Machine.—*See* **Armour Plate.**

Armour-Plate Mill.—The machinery and appliances employed here differ chiefly in their greater mass from those in the ordinary plate mill. The two may be combined, but armour-plate rolling results in some roughening of the rolls, which make it difficult to turn out smooth plates in the same rolls. Properly, therefore, the two sets should be distinct, even though operated in the same shop.

An armour-plate mill includes, besides the roughing and finishing rolls; engines, and boilers, an ingot furnace, reheating furnaces, annealing furnaces, shears, plate-straightening machine, cooling bed, overhead travellers, roll lathe, &c.

The armour-plate rolling mill seen in Fig. 146, Plate IX., is driven by triple engines of the vertical marine type, of 10,000 HP. The housings of the rollers are of forged steel—in fact, they are themselves large armour plates with the centre cut out to receive the roll chocks. The main rollers are 4 ft. 2 in. diameter, by 13 ft. 6 in. on the face, and are hollow forgings made of Whitworth fluid pressed nickel steel, each roller weighing 65 tons.

One of the largest mills in existence is that at Creusot. The following leading particulars will afford some idea of the massive scale of the plant and machinery, by means of which armour plates of from 60 to 65 tons are produced, and ship and boiler plates up to 65 ft. 7 in. long, or 13 ft. 7 in. wide, or circular plates 13 ft. 9 in. diameter.

The roughing and finishing rolls each measure 3 ft. $11\frac{1}{4}$ in. diameter, by 13 ft. $11\frac{5}{16}$ in. long, with necks 2 ft. $5\frac{1}{2}$ in. diameter, and 3 ft. $11\frac{1}{4}$ in. long. Each roll weighs 42 tons 12 cwt. They are carried in standards of 54 tons weight, operated by massive screws $13\frac{3}{4}$ in. diameter outside the threads, and of $1\frac{9}{16}$ in. pitch; to turn which a reversing electric motor, working normally at from 10 to 12 HP., is used. A twin cylinder reversing steam engine drives the rolls, having cylinders 5 ft. 7 in. diameter, with a 4 ft. 11 in. stroke, the reversing of which is done by an auxiliary steam engine.

The main reversing gears on the engine have the usual double helical teeth. They measure over 3 ft. on the face, and are of nickel steel. The wheel weighs 47 tons, and the rim is cast distinct from the centre.

The feed rollers have their mechanism below the floor level, the top edges standing only $2\frac{3}{8}$ above the level. These measure $28\frac{3}{8}$ diameter, and make on an average 12 revolutions per minute, and require an engine working at 35 HP. to drive them. Underground galleries receive the scale, and through which it is removed.

Five reheating furnaces are erected, one of which is for the reception of the ingots. These are coal-fired, and have air blast. The areas of the hearths of these vary from 144 sq. ft. to 205 sq. ft. The waste gases from them are utilised to heat water-tube boilers, most of which are fitted with economisers. Cranes of from 8 to 85 tons capacity serve the shop areas. A large cooling area is left, where plates are inspected after they have cooled down. They then pass to the shearing machines where they are cross-cut, and shorn at edges, and test pieces taken. These have their feed rollers worked electrically.

Annealing furnaces, and a plate-straightening machine are used for boiler and ship plates.

The roll lathe has its centres $37\frac{3}{8}$ high. It has forty-eight different speeds, from 0·26 to 26 revolutions per minute, and is designed for using tools of high-speed steel.

Armour-Plate Press.—There is no special form of press used for this work, the ordinary vertical press of several thousand tons power being employed. It is used for slabbing, bending plates for turrets, and curves generally. An illustration is seen in Fig. 147, Plate X. *See* **Forging Press,** for general construction.

Armour-Plate Shop.—The shop in which the planing, drilling, grinding, &c., of these plates is done. An illustration is given in Fig. 148, Plate XI., and the nature of the operations is described briefly under **Armour Plate.**

Fig. 148.—Armour-Plate Machine Shop. (Messrs Vickers, Sons, & Maxim, Ltd.)

To face page 196.

Armour Plates — Planing Machines for.—These are of a special character, more by reason of their dimensions and functions, than in general construction. They are of the familiar type, with housings, and cross rail carrying tool boxes over a movable work-table travelling under the tools, which is rather remarkable considering the immense mass. Two of these are shown in Fig. 149, Plate XII. In the machines used at Messrs Vickers' Works the tables alone weigh 30 tons, and as these frequently carry a plate of 30 tons, that means a moving mass of 60 tons. To save the non-cutting stroke, a cut is taken in both directions of movement by having tools with double faces. Side tool boxes are fitted, and provision is made for a cross traverse cut. Some machines of this class have worm gears for angling the heavy tool boxes. To avoid having to move so great a mass, big machines are made in which the cross rail and housings travel over the work laid down in a pit between the ways along which the housings travel. *See* **Pit Planing Machines**. These are valuable for planing the faces of plates.

For planing bevelled edges, the Breast Slide Planer is used. These are seen in the photo, Fig. 148, Plate XI. The machine derives its name from the fact that the tool boxes are carried on a slide which swivels on trunnions in the head, and which can be set thereby to various angles. Here the plate is fixed and the tool boxes traverse. It is therefore a type of side planing machine. There is also another kind of side planer used in which irregular shapes and curves are planed, controlled by a templet or former.

Armour Plating.—The first battleships were armoured with wrought-iron plates of from 3 to 4½ inches thickness. As the weight of this bore but a moderate proportion to the displacement weight of the vessels, it was possible to encase the ships wholly in armour. The development of heavier guns and the substitution of elongated projectiles for round shot soon rendered necessary an increase in the thickness of the armour, and its restriction to, or concentration over the more vital areas of the vessels. In the struggle between guns and armour thus commenced, it became necessary to abandon the old broadsides of light guns and replace them with from two to four very heavy guns, protected behind armour plating. These in time were supplemented with secondary batteries of quick-firing guns, also protected. In the course of these developments the pendulum has swung back to the substitution of a lighter class of gun for the heaviest. In British battleships the 12-inch gun has displaced the 16¼-inch and the 13½-inch. But the guns of lesser weight and smaller bore have a higher muzzle velocity than those which they have displaced.

Simultaneously with these developments the locations of armour plating have been subjected to a constant series of variations. In the present practice the locations of the guns are protected by belts of thick plating on the sides of the hull amidships, and around turrets or barbettes, and over and under the gun decks, while the remainder of the vessel's length is covered with thin plating. The reason is that projectiles piercing fore and aft would not put a ship out of action, but if the big guns were disabled or their gunners killed, or the engines or boilers damaged, the vessel would be helpless.

The United States battleships have a belt 11 inches thick above, tapering to 8 inches below, and a 3-inch armoured deck, on the slopes, and 1½ inches on the flat. Some of the British ships have 9-inch belt armour, and a 3-inch deck on the slopes. The Japanese *Hatsuse*, sunk August 1904, had a 9-inch belt, and a 3-inch deck; the French *Suffren* has an 11·8-inch belt and a 2·7-inch deck. Secondary armour ranges from 6 to 7 inches in thickness.

Arms.—*See* **Guns, Small Arms.**

Aron Meter.—*See* **Meters—Electrical.**

Arrangements of Shops.—*See* **Factory Arrangements,** and the various engineers' shops under their special heads.

Arrastra.—A machine of simple construction used in some of the Mexican mining districts for crushing quartz and effecting amalgamation of the gold. It is of service also in testing the value of veins of quartz. Essentially it consists of a circular vessel built of wood or metal, or composed of rough stones, and having a bottom of flat granite stones which receives the quartz. Over this, granite mullers are dragged in a circle, being suspended from a cross arm,

and moved round by mules, or by belt power actuating bevel gears. The work of amalgamation proceeds by the addition of water and mercury for several days, until sufficient amalgam accumulates for subsequent treatment.

Arris.—Denotes the keen angle formed by the meeting of two surfaces at right or other angles. To "take off the arris" is a common shop expression to denote the removal of the angle, as in chamfering, or in imparting a convexity or "rounding" to edges for neat appearance. Arris is prefixed to terms in building, as arris fillet, arris rail, arris gutter, each denoting a Vee section, arris-wise signifying a diagonal saw-cut through a square section, producing two triangles, and in bricklayer's work, denotes tiles laid in a diagonal direction.

Arsenic (symbol, As; comb. wt., 74·9; sp. gr., 5·7).—A brilliant metal of steel-grey colour, which, though sometimes found in the free state, is generally combined with iron pyrites, nickel, cobalt, copper, sulphur, or other elements. It is regarded as a connecting link between the metals and the non-metallic elements, resembling antimony and bismuth in some respects, and phosphorus in others. The separation of the metal is effected first by roasting the ore, or exposing it to a current of air in a reverberatory furnace, when the arsenic combines with the oxygen of the air, forming arsenious acid or arsenic trioxide As_2O_5 which passes off in vapour into flues, where it is deposited. The metallic arsenic is prepared from this by mixing it with charcoal and sodium carbonate, and heating in a closed crucible; arsenic condenses in the solid form, in the upper part, which is kept cool. Arsenic forms two oxides, and three sulphides, and unites with chlorine, bromine, iodine, and hydrogen.

Arsenic alone possesses no interest to the engineer. But when it enters into combination with metals its influence becomes deleterious, or beneficial in different cases.

With regard to steel, Mr Stead's researches would indicate that specifications are sometimes needlessly strict in regard to the minimum amount of arsenic permissible. In steel used for structural purposes he found that arsenic when present in quantities from 0·1 to 0·15 per cent. has no effect on the tenacity and ductility, and at 0·2 per cent. its influence only just begins to be perceptible. Though rolling and forging are not affected by the presence of rather large quantities of arsenic, very small amounts suffice to render welding difficult. Only, therefore, when steel has to be welded is the presence of arsenic up to the usual amount common in mild steel, namely, 0·1 per cent., prejudicial. Arsenic possesses the property of rendering metals more fusible, and it is capable of combining with all metals.

Arsenic forms true alloys with copper. Its presence lowers the melting point of copper uniformly, down to about 14 per cent. addition. Then a steep fall in the freezing point curve occurs, reaching its lowest at 685° Cent., at which point the alloy contains 19·2 per cent. of arsenic. This has the formula Cu_5As_2. A 22 per cent. of arsenic alloy freezes at 708° Cent. The temperature gradually rises to 747° Cent., with an alloy containing 28·34 per cent. of As, with the formula Cu_3As. The next freezing point occurs at 810° Cent., with 32·2 per cent. of As, and formula Cu_5As_2. The temperature then falls to a minimum with an alloy having about 35 per cent. of As. It then rises to 740° Cent., with 37·24 per cent. As, and compound Cu_2. Thence it descends to 702° Cent., with 41 per cent. of As, beyond which direct combination scarcely goes.

Artesian Well Boring.—The original term "artesian" applied to wells made on this system in the province of Artois, the ancient Artesium, is now applied to all wells that are drilled or bored by special tools and not dug. The bored well is thus generally associated with small diameters, though wells of upward of 7 feet diameter have been bored on the artesian system, and even mine shafts have been thus constructed through water-bearing strata in order to avoid the trouble and expense of pumping. The subject will be found treated at length under **Bore-Holes.**

Articled Pupils.—These are a class apart from **Apprentices,** in the possession of facilities for the acquisition of a comprehensive knowledge of one of the great branches of engineering, civil or mechanical, as a preparation

for a professional, or a manufacturing career. The training in each case must be both wide and thorough to be of much utility, hence there is a difficulty in attempting to treat the subject in a concise manner. The differences between the professions of Civil Engineering and Mechanical Engineering will be found treated under those headings, so that this article need only deal with the actual methods of training adopted.

Each of these has two aspects, that of the theory, and of the practice, both equally essential, though much more attention is often devoted to one than to the other. This is due to the natural bias of the pupil's mind, or to that which he receives in the offices, college, or works in which his early training is given. It is very difficult to break with the impressions of the first few years of life, even though subsequent experience might make one wish these had been more utilitarian in character.

What renders either branch of engineering so difficult of acquisition is that it involves the practice of several crafts, operating in a large number of dissimilar materials, introducing at every step the applications of nearly the whole circle of natural scientific facts; that it is a very progressive profession; and finally, that it is subdivided more or less sharply into several different branches, which renders specialisation necessary. So that a man must first acquire good general knowledge of the basis of his intended profession or occupation, and then elect to specialise in some one or more of the great departments of the same. The locomotive engineer does not combine with his own practice that of the mining engineer, nor of the machine tool maker, nor of the gas-engine builder, or the electrician. It is not that one is ignorant of the practice of the other, for no man can afford to be uninformed on any great section of the profession, but that his knowledge of one is special, of the other general only, though workable and practical if the necessity arises for the application of his knowledge. Engineers must gather a vast amount of information—the necessity for this is forced upon them constantly, or they will make costly blunders.

There is no alternative to the binding of pupils, as there is in learning crafts. A pupil is articled for a term of years, and has to pay a stiff premium, which ranges from £50 a year upwards. Neither does this carry with it any responsibility for direct instruction on the part of the firm who draws the premium. It simply gives the pupil the privilege of spending the period covered by his articles, in the offices and shops, with the opportunities which that affords of acquiring knowledge. It is therefore only in a loose sense a special training, for such training as there is depends mainly, almost wholly on the efforts of the pupil himself. If he is receptive, he has ample and invaluable opportunities to learn. He has no unreasonable restrictions placed on his movements, or on his questionings, or personal labours; information and instruction are always forthcoming, and freely given. But the indolent pupil may, and often does go through a term of years and emerge a wastrel, and thus pupilage has frequently become a byword for failure and ignorance.

A pupil who intends to succeed has no time to waste. The usual period covered — five years—is all too little for the work that has to be got through. There is no such thing as dismissing the works from one's mind on leaving office or factory, for evening studies must supplement the day's duties. Book studies cannot be pursued in the midst of daily tasks, but must be reserved for the leisure hours, that are only so in the sense of being more leisurely than the day. No one can hope to become a successful engineer who does not combine study with work, and therefore one must be prepared for double tasks and strenuous labours in each.

Of the two, the civil engineer's pupil should apply himself to a wider range of study than the mechanical, because to the design and construction of great public works he has to add that of the mechanical details of machinery of many kinds. Many do not combine the two thus, but rely on others for the mechanical side of the work. These have been trained in the civil engineer's office, and gathered experience on public works without having passed through the workshops. This is the difference between the training of the civil engineer simply, and that of the mechanical engineer. But all the great civil engineers have, and

must in some way gather an intimate knowledge of the working of nearly all kinds of machinery, enormous quantities of which are employed in the construction of, or in the operation of great public works. These include docks and harbours, with their equipments of hydraulic, steam, and electrical machinery, water works, sewage plants, pumping stations, bridges, and viaducts, and so on, each of which presents totally different sets of problems.

The time occupied by articled pupils with a civil engineer is spent partly in the drawing office, partly on public works. That occupied in a manufactory is divided between the office and the several shops, which constitute the works. There is no exact rotation of, or sequence observed; but it varies in different firms, and in the same firm. The predilections, and wishes of pupils, are frequently respected, and the aim also is not to have too many pupils crowded in one department at one time. The total period spent in any one shop, and in the office varies also. Very often the time occupied in the office is divided into two portions; the first, before going on public works, or into the shops, the other subsequently. In this, the idea of the sandwich system will be recognised, and it is the best, because theory and practice become of mutual assistance. With regard to the shops, the time spent in either one is varied if a pupil desires to gain a more intimate knowledge of one than of others, or if he wants to omit any entirely. Frequently the dirty foundry is neglected, though this is a mistake. So is the smithy, and boiler shop, the principal attention being given to the pattern department, the turning, machining, fitting and erecting.

The omission of either of the shops from the curriculum would be unjustifiable, but for the fact that pupils have the run of the whole works, being at liberty, in reason, to observe and make notes on any of the operations going on in any of the departments, and to witness tests, and ask questions of the men, foremen, and principals.

The period spent in any one shop rarely exceeds a twelvemonth, and six months is more frequent, leaving from a year to two years for the drawing office, which is little enough.

From this point of view of time occupied in a shop the question of skill in handicraft arises. It is obviously impossible for a youth to acquire any large degree of skill in the handling of tools, and the production of work, in the course of a few months. But it would be a mistake to hold that the acquisition of such skill should be the primary object in view. The pupil is not training to earn his living as a craftsman, but in the larger field of engineering as a whole. His aim should therefore be to understand the processes and operations going on in all the shops, rather than to acquire personal dexterity in any one. His high premium is not paid to enable him to become a patternmaker, or a moulder, or a turner, or fitter, but to become an engineer in the broadest sense. He should acquire enough knowledge of the work of every shop to know how to supervise and direct intelligently, and not be fooled by employees or contractors in after years.

The nature and scope of the studies which the articled pupil has to pursue will be found treated under **Civil Engineering**, and **Mechanical Engineering**. The character of the work done in the different shops in the works is discussed under their respective headings.

Artificial Draught. — *See* **Forced Draught, Induced Draught.**

Artificial Magnet.—*See* **Magnet.**

Artificial Seasoning.—*See* **Timber Seasoning.**

Artificial Stone.—*See* **Concrete.**

Artillery.—*See* **Guns.**

Arts.—Fine arts and mechanical arts are included in this term, though often the former only is assumed. Art is a combination of skill and knowledge which produces something which did not exist before. It requires both manual and intellectual effort. In fine art the latter is assumed to be a greater factor than the former. In mechanical art the reverse. In both cases a combination of intelligence and manual skill is necessary. This combination when applied with a definite purpose to inert material is art. In the broad sense of the term all the processes in the practice of engineering are art; but the more mechanical the work and

the less the skill required, the less would it be thought entitled to be considered as art. It is then art of a low order as compared with fine art where a comparatively high ideal is sought.

Asbestos (Gr. *asbestos* = unquenched).—A mineral which in the true or Italian asbestos is a variety of hornblende. But the Canadian variety is said to be a serpentine rock called chrysolite. Asbestos, and its fire-resisting qualities, was known to the ancient Greeks and Romans. The bodies of the dead who were burned were sometimes wrapped in cloth of this material, so that their ashes should not mingle with those of the wood of the funeral pyre. But the modern use of the material dates from 1871, when a works was established in Glasgow.

Although asbestos occurs in nearly all parts of the world, that of commerce is mined only in Italy and Canada.

It is mined in Italy in the Susa valley, over an area of about 10 square miles, and at a height of from 6,000 to 10,000 feet above sea level; in the Aosta valley between Ivrea and Chatillon, a distance of nearly 30 miles, and covering a large area. A third district is situated in that part of Lombardy known as the Valtellina, the area of mining being about 40 square miles. The finest qualities of the mineral come from this district. As the shafts and galleries in the mines deepen, the quality of the asbestos improves. Canadian asbestos occurs in veins in portions of the belt of serpentine rocks in the eastern townships of the province of Quebec. The best kinds come from the districts of Thetford, and Black Rock, about midway between Quebec and Sherbrook. Elsewhere, what are known as second and third grades chiefly occur, the utilities of which lie mainly in non-conducting coverings for steam boilers and pipes, and for roofings. The fibres of asbestos traverse the rocks in veins in all directions. The bundles seldom exceed from 1 to 2 inches in thickness. Blasting is employed to disintegrate the rock, after which the pieces are broken up, liberating the mineral in the form of long and short threads, and powder, in which varieties it is exported as No. 1, 2, and 3 grades. The long and short fibres, and different qualities, are separated and kept distinct, the first for yarn packings, tapes, and cloth, the second for non-conducting compositions. The asbestos powder is used for fireproof paints. The blocks of fibre or rock are first broken up and passed to shaking machines, where the long fibre is separated from the short, and from the particles of rock. The long fibres are subsequently carded, and condensed, and spun into threads to be woven and braided into yarn packings, tapes, and cloth, and afterwards made up with india-rubber into woven sheeting, tapes, and rings, rolled cloth, and square packings. The short fibre is worked up into millboard, and boiler, and steam-pipe coverings. These are thoroughly mixed with various binding materials into the form of pulp, which both lighten and cement the asbestos basis. Hydraulic pressure is used, followed by drying. The paints manufactured from asbestos powders are acid-resisting, and partly fireproof, so that risk of fire is lessened by their use.

Asbestos Goods.—Asbestos millboard is used for making flanged joints. It is a rival to indiarubber for the same purpose. Sheets are usually sold measuring 40×40 inches, and in various thicknesses, from $\frac{1}{32}$ to 1 inch thick. Its weight is less than half that of rubber, and only half the thickness is necessary. It is also made up into rings for flanges and tubes, for electric light leads.

Metallic cloth is a mixture in which the asbestos is reinforced with wire, which is capable of withstanding high pressures both of steam and water, and is suitable for manhole, mudhole, and hydraulic joints. It is used for fireproof curtains for theatres, and for screens.

Asbestos sheeting is asbestos cloth treated with a solution of indiarubber. It is not so suitable for high pressures as the metallic sheeting. Tapes are made from the sheeting for joints that have to be frequently broken, like those of manhole and mudhole doors, taking the place of hemp gasket, and red lead.

Asbestos gland packings are made of square section. Strips of soft metal are bent into corrugations and enclosed in the asbestos body. In another form an asbestos warp, and wire weft are woven, in another every asbestos thread encloses a core of fine wire or is wound with wire. Hydraulic packings have an elon-

gated core of vulcanised rubber, enclosed by a covering of woven wire asbestos. Packings are built up both in square and round sections. They are made of sheeting and cloth. In some cases self-lubrication is ensured by the addition of soapstone, or by a carbonising process.

Asbestos is twined into the form of fine thread, of coarser cord, and of ropes, of which last, fireproof ladders are made. Tubing is made to withstand the action of acids. Gloves, leggings, and aprons are made for furnacemen.

Asbestos is made up into fireproof putty for use in place of red lead. In the form of cement it is employed for the protection of conductors in electric light installations, and for use in chemical works, in retort and other joints. In the form of balls and fibres it is employed largely in gas fires. As felt or sheathing it is a fireproof lining for floors and partitions.

An important class of asbestos goods is that of boiler coverings. Asbestos is mixed with various other materials, and under numerous fancy names is sold for specific purposes in connection with boilers and steam pipes. Their value lies in their non-conducting and heat-resisting qualities. It is also essential or desirable that the composition shall possess good adhesive qualities, and set hard, and not lose its nature for many years. It must also be neutral, in order to exercise no chemical action on the surfaces of the metal with which it is brought into contact. Asbestos is mixed with magnesia, combining toughness and durability with the lightness of magnesia. It is used with fossil meal, and with felt. Another preparation is of a siliceous nature, specially adapted for flues and for the conservation of heat. These compositions are mixed with water to about the consistency of thick mortar. The following are the instructions given by the United Asbestos Co., Ltd. :—

"Clean away all paint, oil, dust, or dirt from the surface of the parts to be covered. Mix the composition with water to about the same consistency as thick mortar, and rub over the hot surface with same: next apply in small patches about 2 inches apart; when these dry and harden, apply the composition in layers of about ½ inch thick, each layer to be dry and hard before the next is put on. The last fine layer should be nicely levelled off with trowel and straight-edge before it has time to harden, and finished in this way to the required thickness. In covering the under surfaces of boilers, pipes, &c., it is best to rub them with the composition, holding it until the heat of the pipe draws the moisture, when small pieces of fibre will act as a key for the succeeding layer. We recommend a thickness of 1 to 2 inches, or in some cases more, according to the steam pressures or temperatures of surfaces, and the quality of the composition being used.

"When the pipes or vessels to be covered are subject to much vibration, fine galvanised binding wire or wire netting should be fixed around the covering at about two-thirds the thickness of the finished covering, the wire being concealed by the last layers. When the covered surfaces are exposed to the weather, two or three coats of special black varnish should be applied with a brush and renewed from time to time as required. Common tar is not suitable for this work. When using the higher qualities of composition, extra care must be exercised in applying in thin coats and ascertaining that each coat is perfectly dry before the next is applied; if these precautions are not taken, the composition will not harden properly. No paint or varnish must be applied before the composition is quite dry and hard."

A special form of non-conducting covering is made removable for parts that have to be uncovered at intervals more or less frequent, and which for that reason are often left unprotected. Flanges, bends, tees, portions of boilers and boiling vessels, tanks, &c., are cases in point. The radiation from flanges and bends is large. These can be covered in sections and secured with a brass or steel band. For boilers and boiling vessels these coverings are supplied flat, and curved, in sheets of various thicknesses, from ½ in. to 2 inches, termed mattresses. Compound coverings are used also, the inner consisting of asbestos wadding which adapts itself to joints and rivets, and is itself embedded in a hard cellular covering. Removable coverings are also made for the cold pipes used in refrigerating systems, to prevent the accumulation of frost on the outside. In these, hair felt and waterproof

paper alternate, the whole enclosed with canvas, laced at the joint, or enclosed with bands of metal. Pipes are also lagged with asbestos rope coiled round and covered with canvas, so permitting its use on pipes of any diameter. Ropes are also used for removable flange coverings retained within metal covers. Entire valve bodies are enclosed in removable coverings, because of the difficulty of enclosing the flanges alone when in close proximity to the bodies.

Ash (*Fraxinus;* Order *Oleaceæ;* A. Sax. *æsc;* Ger. *esche;* sp. gr., 0·84; weight of a cubic foot, 52 lb.; colour varying from light to dark in different specimens).—A tough, flexible, coarse-grained wood, common in Britain, Asia, and America. It is suitable for all purposes where elasticity and flexibility are required, and where shocks have to be sustained. It is better for most purposes when felled young than when matured. It is used for some wood parts in machinery, and for hammer shafts, being tougher than any other European timber; also largely utilised by coachmakers and cartwrights, and for agricultural implements and ships' blocks. Ash varies a great deal in character, according to the situation and soil it grows in. It is durable when kept dry, but does not stand moisture well, and soon rots if alternately wet and dry. It is suitable for the cogs of mortice wheels, though inferior to apple wood, or beech.

Ash.—The ash and clinker left from the combustion of coal becomes a nuisance when the quantity yielded is large. The value of coals is partly measured by this test. Clinker destroys the grate bars, and the trouble of clinkering several times in a day, and the expense of getting rid of the ash, are sufficient reasons why the selection of those coals which leave little ash is to be recommended on the score of economy, even though they are more expensive than the others. Welsh steam coal yields only between 3 and 4 per cent. of ash, while slack will produce as much as 20 per cent. Heat is lost in the ash, and clinker to the extent of from 1 to 2 per cent. *See also* **Boiler Testing.** One of the advantages of **Liquid Fuel** is its freedom from ash.

Ash-Crusher or Cinder-Crusher.—A machine used in large brass foundries for the purpose of crushing the furnace ashes and the mould skimmings, and separating them from the particles of metal entangled therewith. The crushing is effected by a heavy roller. In Hill's machine the cylinder is rotated on a horizontal axis, making from 40 to 60 revolutions per minute, and being driven by spur gearing. The longitudinal section is that of two truncated cones placed base to base, and within it a heavy solid roller of similar longitudinal section revolves loosely with the barrel, crushing the ash and cinder. The roller has deep longitudinal groovings which scoop up the material from below, and carry it round to be re-pulverised. Ash-crushers are made either for wet or dry processes. If wet, a water pipe is introduced through the axis of the barrel, with a regulating valve. If dry, an exhaust fan is fitted by which the dust is withdrawn, leaving the heavier metal behind. *See also* **Ball Mill.**

Ash-Ejector.—This is an ash-hoist of a special type, which is used to a slight extent in vessels where the boilers are worked under forced draught with closed stoke-holds, and where ash-skips have to be passed through an air lock. The ashes and clinker are ejected into the sea by means of a force pump, or a jet of water. They are sometimes ground and mixed with water, sometimes simply ejected by water pressure while in their ordinary condition.

In one type, the Trewent, the ashes are tipped into the ejector through a hopper, whence they descend into one leg of a V-shaped pipe. A jet of water brought in from below at a pressure of from 170 to 260 lb. drives out the ashes through the other leg into the sea. In the De Maupeon ejector the ashes are ground and mixed with water. They pass down between two jaws, one fixed the other movable, resembling somewhat the jaws of stone-crushers. Water is then admitted among the pulverised mass, and the whole pumped out by the trunk piston of a force pump, operated by a steam cylinder above. The chamber below the piston has two indiarubber valves which control the passage of the stuff to a vertical discharge pipe.

Ash-Elevator.—*See* **Ash-Hoist.**

Ashes.—*See* **Ash, Ash-Hoist.**

Ash-Hoist.—Ash-Hoists, or Elevators, or Hoisting engines are used for lifting the ashes from the stokeholds of ships. They are generally driven by small engines, usually of the vertical, or inclined types, and with double cylinders to avoid dead centres. The size of the cylinders ranges from 4 to 6 inches diameter, and 8 to 9 inches stroke. The drum is driven direct from the crank shaft, or through friction wheels of Vee'd section.

Ash-Hoisting Engines.—*See* **Ash Hoist.**

Ashlar or **Ashler.**—A term used in masonry and in carpentry. In masonry it means squared stone used for building, in opposition to irregularly shaped stone. The character of the squared stone is also distinguished by suitable adjectives preceding the name ashlar; such as smooth or plane ashlar, having a smooth face; tooled ashlar, having its face ploughed with tool marks; rusticated ashlar, having a rough irregular face standing out beyond the joint faces which are a margin of level surface; bastard ashlar, a thin face of squared stones backed with bricks or rubble. In carpentry ashlar means the short vertical bars of wood used in garrets to cut off the acute angle between floor and ceiling, and to which laths are nailed.

Ashlaring.—The process of building with ashlar. Sometimes also used in the same sense as ashlar.

Ash-Pan.—The pan beneath the fire-box of the boiler of a portable engine.

Ash-Pit.—The pit beneath the fire-grate of a stationary horizontal boiler, into which the ashes fall, and through which most of the air required for combustion enters.

Asphalt.—A substance of a black, or brownish-black colour found in numerous districts, in varying states, ranging and merging insensibly from the brittle, to the pitchy condition, known as mineral tar. It is a product of the decomposition of vegetable and animal substances. The principal constituent is carbon. The deposits occur largely diffused, chiefly in tropical and sub-tropical regions, in the interstices of rocks. In Trinidad there is a lake of asphalt having an area of 99 acres, and of unknown depth. Cuba and Peru furnish supplies of the mineral.

Asphalt stone is a limestone impregnated with from 7 to 20 per cent. of the material, the principal beds being in the Val de Travers, Neufchatel. These have been quarried, for use on pavements and roadways. Two processes are employed, the mastic, and the compressed. The difference between these two lies chiefly in the pressure exercised, by rolling in the asphalt prepared while hot. Asphalt was first used for street paving in London in 1869. A cement is first made of the asphalt by heating it in ovens, or in furnaces to a temperature of about 320° Fahr., during which time it is agitated by stirring, or by compressed air. Sand is heated to 380° Fahr. and mixed with the asphalt, and laid over a foundation of concrete, and tamped or rolled in. Where large quantities of this work are done, plants are obtainable, comprising either furnaces, or melting kettles, or steam-heated tanks, sand heaters, mixers with beaters, fire wagons for heating the tamping and other tools.

Assaying.—Assaying is a branch of Quantitative Analytical Chemistry, designed to give prompt and accurate information as to the quantity of metal contained in certain ores, those of Gold, Silver, Lead, Tin, Copper, and Iron. It also affords a very valuable guide to the efficiency of the different processes employed in recovering the metals from the ores, and of the actual value, where required, of quantities of metals offered for sale.

The metals are found in nature, sometimes in the form known as native, that is in a finely divided metallic state, but more often in combination with other elements, and usually several compounds of the metals, sometimes of several metals, are found in one deposit. In all cases the quantity of the metal is very small, in proportion to the mass of the rocks from which it has to be extracted, and the various processes known as metallurgical, are designed to separate the other matter, the waste, from the metal itself. The assay, if properly carried out, enables the metallurgist and the engineer to estimate what plant will be required to deal with the ore, and what quantity must be dealt with to make the process a profitable one. It is unfortunately quite possible to produce even gold, at a cost that will not pay for production, the price of

the metal finally obtained not covering the expense incurred in obtaining it. The assay also assists the manager of any metalliferous mine, or should do, in certain cases, in laying out his workings. Mining knowledge will do a great deal, but a check, such as is provided by constant tests of the mineral being worked, is invaluable. Also as the mineral passes through its various processes, the assay should show if any undue waste is being made, and if the full possible quantity of the metal is being obtained. This is of great value, as all metallurgical processes are wasteful. It will be seen from the above that the two great requisites of assaying, and of assayers, are accuracy, and rapidity.

Assaying may be conveniently divided into two branches, both of which are of practically equal importance, though one only requires care, and a little experience, while the other requires equal care, more experience, and considerable knowledge. The two branches are:—Sampling;—and Testing, or Estimating. The latter is the real process of assaying, as it is understood, but the former is equally important. What is required in the sample to be tested is an accurate representation of the quantities of metal that will be obtained from the ore, when all the processes through which it is passed have been completed; and not an estimate of the best the ore can do, or the richest portions it is likely to produce.

It is almost an axiom with men who are experienced in the finance of metalliferous mining, that the assay value is nearly always higher than the value actually obtained, and the reason of this is obvious. If an assayer has skill and experience in handling the very delicate appliances he uses, if he is provided with proper appliances, and if he is careful in using them, he should obtain the very utmost possible return from the quantity of the mineral upon which he operates. On the other hand, the processes through which the mineral passes are from various causes all wasteful. A good deal of the process is necessarily carried on by the aid of unskilled labour, with the often attendant want of care. Machines, which are designed primarily to save labour, are rarely flexible enough to do all that a careful man will do, under similar conditions, on the same work, and there are other causes, which metallurgists are familiar with. Hence it is of the utmost importance that the samples taken from assaying shall represent the actual through and through mineral; that they shall present a fair average of *all* the mineral that is being worked at the time, or from the place from which the sample is taken. For this reason, old Cornish miners have long had a system of sampling, especially designed to be absolutely impartial, and to leave out the personal equation altogether. In sampling, it will readily be understood, expert knowledge may actually be a drawback, as it may lead the sampler to pick out good samples, where good and bad should be sampled alike. In the first place, the quantity of ore from which the final sample is taken, should be as large and as representative as possible, a couple of tons or thereabouts, and it should be taken from every part of the ore heap that is to be sampled, by digging in with a spade, at every part of the heap, and by equivalent methods. One simple plan, that can be carried out by an ordinary labourer, which has the merit of absolute impartiality, is:—The ore is heaped up in any convenient manner, and a tape line is passed over it, round it, and across it, in every way that the ingenuity of man can devise. Samples are taken wherever a foot-mark touches the ore, say at 1 foot, 2 feet, 3 feet, and so on. After every variety of line has been made use of the ore is turned over, rearranged, and the whole gone through again.

This method is used, in some cases, for sampling iron ore. When a sufficient quantity of ore has been obtained, it is put through the process known as "coning, and quartering." The ore reserved for assay, after being crushed to a size going through $\frac{3}{4}$-inch mesh, is heaped up into the rough form of a truncated cone, and the heap is then divided into four, with a spade or any convenient tool, by making diametral lines across the base. Two of the quarters, those opposite each other, diametrally, are thrown back on the ore heap that is being worked, and the remainder is formed into a second similar cone, which is again divided in the same manner, two quarters again being rejected, this time the two occupying the posi-

tions of those which were retained at the first quartering. The mass has now been reduced to one-fourth that with which the assayer started. It is now crushed to a size that will pass through a sieve having $\frac{1}{4}$-inch mesh, thoroughly mixed, and quartered down to half its bulk, an eighth of that at the commencement; the sample reserved is crushed to pass through an 8 mesh sieve, that is having 8 meshes to the linear inch. It is again thoroughly mixed, and sampled down in the same way to one-sixteenth the original bulk, and weight; crushed to pass through a 12 mesh sieve, again mixed, and sampled down to one thirty-second of the original, and again divided. The sample is then crushed to pass through a 30 to 40 mesh sieve, and sampled down to from $\frac{1}{1000}$th to $\frac{1}{2000}$th of the original, a split shovel being used in the later stages.

This shovel is constructed with several teeth, each formed like a gutter, and the ore which falls between the teeth is taken for the first sample, then that which is caught by the teeth, and so on. After the last process, the sample is again crushed down to pass through a 100 mesh sieve, or in some cases smaller, and the residue, that which passes through, is spread out on a sheet of glazed paper, oiled silk, or something similar, and thoroughly rolled over and over again at least 100 times. It is then spread out in a thin layer, and divided up into squares. A small sample is now taken, by means of a spatula, a tool provided for the purpose, from each of the squares, the sampler being very careful not to take the sample from the surface, but to dip into each, right to the bottom. The final samples are put up in accurately gauged bottles, and separately estimated. The separate assays should agree within a small percentage. It is important not to lose any dust in any of the above processes, and to weigh very carefully at every step, particularly before the sample goes through the sieve. The final samples, which weigh a few ounces each, should, it is claimed, fairly represent the ore to be assayed.

Estimating.

There are, broadly, two groups of methods of estimating the metal contained in the sample. By dry methods, in which heat is employed, the ore being fused. By wet methods, in which the ore sample is treated chemically, and usually a certain insoluble salt of the metal produced, which is weighed, and from its weight, the weight of the metal in the sample deduced, and thence the percentage, or other quantities required. Gold and Silver are always estimated in ounces or pennyweights per ton of ore, other metals by percentages of the metal in the ore.

Dry, or Fusion Methods.—Only some of the methods used with Lead, Copper, Tin, and Iron will be dealt with in this section.

The fusion methods all consist in adding a flux to the ore, submitting the mixture to the action of heat, and thereby separating the metal assayed for by gravity. By a flux is meant a substance or a mixture of substances that when added to ore, forms with some of the components of the ore a fusible compound, and hence causes the whole mixture to run, when heat is applied, the metal sought being heavier than the other substances in the ore, easily separating from the slag. The substances contained in the mixture submitted to fusion, other than the metal sought, are called the slag, and it is important, in all cases of assaying by fusion, to obtain a liquid slag, the metal then easily separating out.

For Lead, the flux consists of a mixture of the Carbonates of Potassium and Sodium, with some Borax, and Flour, and to this is added some iron, in the form of nails. If the fusion is carried out in an iron pot, the iron of the pot will do as well. The object of the iron is to carry away the sulphur present in so many lead ores, by the formation of Sulphide of Iron. Cyanide of Potassium may also be used as a flux, the cyanide forming with the sulphur a compound of Potassium, Sulphur, and Cyanogen. The process is, however, dangerous, as the fumes of Cyanide of Potassium, or Prussic Acid, are very poisonous. The fusion is carried out in a furnace, usually of the muffle pattern, designed for the purpose, but sometimes in an open furnace.

Other Methods with Lead.—There are two wet methods of assaying lead ores, known as the Gravimetric, and the Volumetric. In the Gravimetric, the ore is treated with Nitric

Acid, the Sulphur contained in it being thereby converted into Sulphuric Anhydride, and combining with the lead to form the insoluble Lead Sulphate, from which the amount of the lead is estimated, by the fact that pure Lead Sulphate contains 68·3 per cent. of Lead. The salts of Iron and Copper have to be dissolved out separately with this method.

In the Volumetric method the ore is treated as in the Gravimetric process, Lead Sulphate being formed as before. The Lead Sulphate is dissolved in Ammonium Acetate, and treated with Ammonium Molybdate, the White Lead Molybdenate being formed, which is carefully estimated in a specially graduated burette.

Copper.—In the dry or fusion process for assaying Copper, a flux is employed, consisting of Borax, Soda, and Bi-Tartrate of Potash, the process being very much the same as with Lead.

The principal wet method, with Copper, is the Electrolytic, the ore being dissolved in a solution of Sulphuric Acid, and subjected to the action of an electric current, the Electrodes being Platinum, the increased weight of the Cathode, the negative Electrode, measuring the weight of Copper in the solution, and therefore in the sample, if all the Copper has been brought down. A favourite form for the Electrodes is, two concentric cylinders, the inner one being the Cathode. Care must be taken, in using the Electrolytic method, to eliminate the Silver, Arsenic, and Cadmium, which would come down with the Copper.

There are two Volumetric methods for assaying Copper. In one, Potassium Cyanide is added to an Ammoniacal salt of Copper, the insoluble salt Cyanide of Copper being formed, which is estimated in the usual way. The ore is treated with a mixture of Nitric and Sulphuric Acids, and then with Ammonia.

In the other method, Potassium Iodide is added to Cupric Acetate, prepared from the ore, Cupric Iodide being formed, and it is then treated with Hyposulphite of Sodium, Hydriodic Acid being formed. The quantity of Copper in the sample is estimated from the quantity of Iodine liberated; one atom being liberated for each atom of Copper.

Tin.—A certain quantity of the ore is taken, and crushed sufficiently to pass through a 40 mesh sieve, and concentrated, the concentrates being roasted in an iron roasting dish in a muffle furnace. The product is treated with *aqua regia;* the product of this, after filtering, is ground to an 80 mesh sieve, and is then assayed with a flux, by heat in a muffle furnace, Cyanide of Potassium being used for a flux by some assayers; a mixture of the Bicarbonates of Potash, and Soda, together with some Borax, and some Charcoal, by others; and Sodium Carbonate, with Lime, by others. The process is similar to that with the other metals.

Iron.—Iron may be assayed by the fusion method, and by two wet methods. In both wet methods, the iron in the ore is all reduced to the Ferrous state, and in one is then treated with Permanganate, in the other with Bichromate of Potassium, the Iron being thereby raised to the Ferric state, the volume of the standard solution required to bring all up being the measure of the Iron in the ore. With Permanganate of Potash, the salt being of a deep red colour, the Iron solution turns yellow, as the Permanganate is added, till all the Iron has been raised to the Ferric state, when the first drop in excess causes some of it to turn pink. With the Bichromate, the solution turns green, and the end of the process is known by placing a drop of the solution on a white tile, and adding Ferrocyanide to it. As long as any Ferrous salt remains, the solution turns blue.

In all cases the metal, or the salt of the metal, is carefully weighed in specially delicate balances, from which even the air is excluded, and which are kept scrupulously free from dust. The percentage of metal in the ore is found by a simple arithmetical calculation, from the weight of ore in the sample, and the weight of the metal or the salt of the metal finally obtained. But it is necessary to be careful, as the sampling proceeds, to see that credit is given for all the metal obtained. Sometimes minute pellets of the metal are obtained in the crushing process, before any particular sieve. These are carefully collected, weighed, and credited, not to the final sample, but to the sample and weight at which they occurred. Thus, if say a pennyweight of metal were obtained at the sample going through the sieve at which the sample

was reduced from $\frac{1}{16}$ to $\frac{1}{32}$, the pennyweight would be credited as a pennyweight in so many pounds the weight of the sample at that stage.

Assembling.—This is a comparatively recent practice in its application to engineers' work, being only possible when an interchangeable system is adopted. The term signifies that all the parts of which a motor or mechanism is built up are brought together finally without any correction by hand fitting; that any parts which are identical in shape and dimensions may be taken at random from a pile, and put together without the assistance of cutting or of scraping tools, differing therein from mechanisms which require the numerous corrections of the fitter.

This ideal is not always fully realised even in shops where parts are nominally assembled, but it is absolutely so in large numbers of mechanisms. Without it, cheap production, and the replacement of worn and broken parts as required by customers, would not be possible.

In order to the realisation of a perfect system of assembling, the machinery employed in the production of the parts must be so designed that the tools and appliances used shall both cut and size, that is embody the dimensions as well as the formation of all similar pieces. If this is not done on one machine, it must be on another at a later stage, *i.e.* a grinder succeeding the lathe, or planer. A familiar illustration is afforded by the **Automatic Screw Machines**, in the use of **Box Tools**, which size as well as shape, and the cutting of screw threads by fixed dies.

And then, to prevent loss of time when the parts come into the hands of the assemblers, the separate pieces are all gauged as they leave the machines. Fixed gauges of various kinds are used, and lads or girls frequently handle them. Even here things are often so arranged that the pieces automatically size themselves, according as they fit, or do not fit gauges, which lie in a course along which they are compelled to travel.

Assembling in its strict and absolute sense is only practicable with the smaller mechanisms, of which Small Arms afford the best illustration. As dimensions increase, the devices used for small work are no longer practicable, neither can the effects of spring, of temperature, and other variables be eliminated. In all machines of medium and large sizes some fitting and adjustments become more or less necessary. Then it is a question whether the work is sufficiently often repeated to make it worth while incurring the expense of working very closely to absolute gauged dimensions, when mutual fitting might be equally well adapted to the case. That is a question which is answered differently by different firms.

The operation of assembling is done on special benches set apart for the work, and it may happen that the assemblers will put together the whole of a small mechanism, or a separate section of a mechanism will be entrusted to each worker, which is more desirable and economical in some instances. Where parts are put into stock largely, the complete fittings may only be made up as required, and the assemblers kept busy on detached portions, which they assemble to the exclusion of everything else. Special devices are employed in connection with assembling, such as boards or trays carrying the detached components of the mechanism, for convenience of picking them out, and special stands to rest the partly completed pieces upon, holding them steady while the assembler is at work. Devices such as indicators and various gauges are also employed, for getting correct distances and positions of related parts, not because the latter are not machined correctly, but because such adjustments are unavoidable in many mechanisms, though not necessarily involving cutting or working by tools. When, however, the latter practice is involved, we step from assembling at once into fitting. Fig. 150, Plate XII., is an example of a modern assembling shop.

Assistant Cylinder.—A small cylinder designed by Mr Joy to relieve the strain on the eccentrics, and the valve gears of heavy marine engines. The dead weight of the slide valve, its inertia, and the friction of the valve on its seating, make up a total which stresses the eccentrics and gears severely, and produces tensile and compressive strains in the valve rod. The assistant cylinder sets up forces equal and

Fig. 149.—Armour-Plate Planing Machine. (By Niles-Bement-Pond Co.)

Fig. 150.—Assembling Department of the National Cash Register Company, Dayton.

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opposite in character to those caused by the weight, inertia, and friction of the valve. It is a small cylinder bolted on top of the steam chest. The slide valve rod passes up into it through a gland and serves as a valve for admitting steam to the lower side of the piston. The piston is hollow, and holes in it in communication with slots in the cylinder valves receive steam from below, which is passed to the upper side of the piston to overcome the tension in the rod due to the inertia, and to start the valve on its downward stroke. The volume of steam thus admitted is adjusted to meet any conditions. *See also* **Balance Cylinder**.

A-Standard.—*See* **A-Frame**.

Astatic Needle.—*See* **Galvanometer**.

Astragal is a moulding or bead used in architecture. It is either applied to the top of a shaft where the capital commences or to the base. It is semicircular in form, with a plain surface, although there are Roman and Greek examples in which the surface is carved into beads or leaves. *See* **Architecture**.

Astronomical Instruments.—The scope of this work does not include the description of these instruments. But there is one branch of the subject with which the engineer has become identified, namely, the construction of big telescopes, of which some account should be given, and that of dividing engines for the accurate division of circles and lines. These will be treated under **Dividing Engines**, and **Telescopes**.

Atlantic Liners.—In sketching the growth of the Atlantic liners from the standpoint of the engineer we outline the history of ocean steamships in general. There are no liners so large or so swift as those which cross the Atlantic, and all pioneer work has been done in that service. That ocean was the first to be crossed by steam, and always on its waves the newest designs have been put to the test, for more than sixty years past. We do not propose to give a detailed account of historical matters that are familiar to most people, but to indicate the epoch-making engineering developments of that history. For the story of the Atlantic liners is one of epochs in engine and boiler design, in auxiliary machinery, in the design and construction of hulls, in the displacement of old materials by new, in safety, speed, dimensions, and accommodation. This is the point of view from which this article is written.

In 1838 the *Royal William*, the *Sirius*, and the *Great Western* made their historic passages across the Atlantic. The *Royal William* was the first to be divided into watertight bulkheads, of which she had four. The beginning of the Transatlantic Companies dates from 1840, when the Cunard vessels began to carry the mails between Liverpool, Halifax, and Boston, backed up by a subsidy of £60,000 a year, and up to the present time this line has never lost a passenger's life. The first vessels of this fleet were of wood, and propelled by engines of 750 HP., the boilers burnt 37 tons of coal a day, the ships occupied from 13 to 15 days in the passage, and carried 115 first-class passengers only. Eight years elapsed before any steamship carried steerage passengers, or before any rivals ventured to compete with the Cunard vessels. In ten years the fleet had grown both in numbers and size, but paddles had not as yet been supplanted by screw propellers. The Inman Line now came on the Atlantic with the *City of Glasgow*, the first iron vessel which proved successful. For the *Great Britain*, though built of iron, and driven by a screw, and the longest vessel then in existence, 1843, was wrecked after having made but two voyages. The Cunard Co. built their first iron steamer, the *Persia*, in 1855. During that period of fifteen years, the power for propulsion had grown from 750 HP. on the *Britannia* to 3,600 on the *Persia*, and the consumption of coal per day had risen from 37 tons to 160 tons. The Cunard Co. adopted the screw propeller first on the *China* (1862). The last paddle steamer of this line, the *Scotia*, was built in this year also.

The period between 1850 and 1860 was a remarkable epoch, rendered so by the building of the *Great Eastern* (1858), only eighteen years after the *Britannia* began running. Forty-one years passed before the length of the *Great Eastern* was exceeded, by the second *Oceanic*. The vessel was before her due time. The engine-power was not sufficient, and her coal consumption was exorbitant, burning fully two and a half times the amount that is burnt on a

modern liner for equal power. The necessary space given up to bunkers, which diminished her paying capacity, and the coal consumption required for her 11,000 HP., with a speed of 13 knots, was fatal to her success, besides which she could not be taken into the docks and harbours of that period. The task which Brunel attempted, with no precedent to guide him, would be paralleled at the present time if the attempt were made to build a ship about 1,300 feet long, to be propelled at from 35 to 40 knots an hour.

During this decade—1850 to 1860—the Inman Line made the innovation of taking steerage passengers, who had previously been compelled to travel by sailing craft.

Between 1860 and 1870, the speeds of liners gradually increased, until the Transatlantic passage became reduced to between 8 and 9 days. The last paddle steamer, the *Scotia*, as previously noted, came out in 1862. In 1869 the first compound engines were introduced on the *Holland* of the National Line. Next year the Cunard Co. fitted compound engines on the *Parthia*, and they were adopted by the Guion Line in 1870. The *City of Brussels* was the first Atlantic liner (1869) fitted with steam steering gear.

The decade 1870-80 was a period of activity. It was rendered notable (1871) by the appearance of the White Star Line with their first *Oceanic*. In the vessels of this fleet, the high bulwarks of the old wooden vessels were abandoned in favour of light iron railings, which when heavy seas were shipped, allowed them to escape freely. The proportions of length to breadth were altered, and were the subject of much criticism, and the saloon was placed amidships. In 1875 the Inman *City of Berlin* eclipsed all other Atlantic craft in size and speed. She was 520 feet in length, her horsepower 5,200, and her speed 16 knots, bringing the passage down to about 8 days. The *Arizona*, of the Guion Line, followed in 1879, with greater engine-power, and made her passages within 7½ days. The same year saw the first steel Atlantic liner built for the Allan Line—the *Buenos Ayrean*. In the same year the *City of Berlin* was the first to be fitted with electric light.

The period 1880-1890 was rich in developments, and now historic names. The Cunard *Servia* (1881) was the first Express liner built of steel, with a cellular double bottom. Her length was 540 feet, and her engines of 10,000 HP. The *City of Rome* (1881) was an iron vessel 600 feet long, with engines of 11,500 HP. In 1881 twin screws were first tried on the *Notting Hill*. The name Atlantic greyhound was first given to the *Alaska* (1882). She was the first to reduce the passage below 7 days. The *Oregon* (1884) brought it below 6½ days. The first Atlantic liner fitted with triple expansion engines was the *Martello* (1884), of the Wilson Line. In 1888-9 the *City of New York* and the *City of Paris* were built, largely of steel, and fitted with twin screws, and with triple expansion engines of 18,500 HP., available for a speed of 20 knots, but at an expenditure of 300 tons of coal per day. But the passage was reduced below 6 days. Forced draught was first applied in the Atlantic service to the *City of New York* (1888). This vessel was the first on which the rudder was placed entirely below the water-line, in which hydraulic steering gear was used, and where fore and aft mid-line bulkheads were fitted, and the closed stoke-hold system was adopted. The Cunarders *Umbria* and *Etruria* (1884-5) were splendid vessels, 500 feet long, and occupied rather over 6 days in the passage. The magnificent White Star liners *Teutonic* and *Majestic* had engines of 17,500 HP., and twin screws. During this period the North German Lloyd entered into the Atlantic service with vessels built in the German yard of Stettin.

The decade 1890-1900 gave birth to the Cunarders *Campania* and *Lucania*, developing 30,000 HP., and burning 500 tons of coal a day each. The *Kaiser Wilhelm der Grösse* eclipsed these in size, and speed, until passed in size, though not in speed, by the present *Oceanic* (1899), which is the first vessel to exceed the *Great Eastern* in length, being 25 feet in excess of that ship, and 80 feet longer than the *Kaiser Wilhelm der Grösse*.

The period from 1900 to the present (1905) has been marked by the increased rivalry of the German lines, the vessels of which have for several years (since 1897) retained the blue

riband of the Atlantic for speed. But the most important fact from the engineers' point of view has been the advent of the turbine-driven ocean liner.

The *Celtic* (1901) was the first vessel built to exceed 20,000 gross tonnage, to be exact 20,880, or 1,965 tons more than the *Great Eastern*. Her length is 9 feet greater, being 700 feet. The *Kaiser Wilhelm II.* (1903) exceeds the *Celtic* in length by 6 ft. 6 in., her IHP. is from 38,000 to 40,000, and she burns about 4,500 tons of coal on a single voyage. Her engines, boilers, and propelling machinery occupy about two-thirds of her length, and there are about 70 auxiliary engines. She has accomplished the voyage from Sandy Hook to Plymouth, 3,112 miles, in 5 days, 11 hrs. 58 mins., averaging 23·59 knots per hour. The cost of speed is well shown by the following table by an Admiralty Committee :—

Speed (in knots)	20	21	22	23	24	25	26
Time of Voyage (chronometer hours)	150	143	136	130	125	120	115·5
Prime Cost	£350,000	£400,000	£470,000	£575,000	£850,000	£1,000,000	£1,250,000
Indicated HP.	19,000	22,000	25,500	30,000	40,000	52,000	68,000
Length (in feet)	600	630	660	690	720	750	780
Displacement (tonnage)	13,000	15,000	17,300	19,800	22,400	25,400	28,500
Coal (in tons)	2,228	2,456	2,912	3,058	3,900	4,876	6,131
Steam Pressure (pounds per square inch)	150	165	181	198	216	234	254
Machinery Department (number of hands)	100	110	125	150	200	260	340

The contract for the two high-speed turbine Cunarders was signed in April, 1904. The dimensions are 760 feet length, and 88 feet beam, giving a displacement, without cargo, of between 32,000 and 33,000 tons. To get a guaranteed speed of 25 knots, between 66,000 and 70,000 HP. has to be developed, with a coal consumption exceeding 1,000 tons per day, steam being generated in cylindrical boilers with Howden's system of forced draught.

The Allan liners *Victorian* and *Virginian*, the first Atlantic liners fitted with turbine engines, reached Halifax after a maiden passage of 7 days 22 hours, and 6½ days respectively, in March and April, 1905.

The following is a brief outline of the story of the engine and boiler developments of this period, beginning with the advent of the Atlantic liners.

The early engines were of Napier's side-lever type, and they continued in use until the introduction of the screw propeller rendered a new design necessary. The leading features of this design were that the heavy portions were situated low down in the hull. Here the side levers were situated, one end of each being actuated by connecting rods operated from the piston through a crosshead, while rods at the other ends rotated a crank on the paddle shaft. This useful type was retained down to 1862, when it was fitted to the last paddle steamer, the *Scotia*. And even after the introduction of the screw, the old engines were retained for some time, with modifications to suit the different rate of revolution of the propeller. As the paddles made from 14 to 18 revolutions per minute, and screws rotated at from 40 to 100, the engines were geared to the screw shaft, which involved placing the engines at right angles with their original positions, or across the ship.

After various transitional designs, including oscillating engines, the inverted cylinder type was introduced, which has remained to the present, as far as the main design, that of overhead vertical cylinders, is concerned. The top-heavy aspect of this design is discounted by the low position of the screw shaft.

All the early inverted cylinder engines were of simple type, but the introduction of compounding, of triple, and quadruple expansion engines, and twin screws, with increase in dimensions, have had the effect of increasing the complexity and mass of these engines. Com-

pound engines, first put into the *Holland* in 1869, and adopted in 1871 on the first *Oceanic*, represented the best practice for about fifteen years, before three expansions were adopted on the way to the condenser. The *Martello* in 1884 had these triples first, followed by the *Aller*, of the North German Lloyd, in 1885.

But high expansions were impossible while the old box boilers, and low pressures remained in use. High expansion is inseparable from high initial pressure. The box boilers never carried above 12 to 15 lb. pressure to the square inch. The boilers of a modern liner carry from 180 to 200.

Not till the introduction of the cylindrical, or Scotch boiler, were higher pressures possible. In 1850 the average was still only 14 lb., by 1860 they had risen to 30 lb., by 1870 to 50 lb., by 1880 to 70 lb. And they would not have gone much, if any higher than 60 to 70 lb., had steel not come in opportunely. Now with plates of steel of $1\frac{1}{4}$ in. to $1\frac{1}{2}$ in. thickness, boilers are safe at 200 lb.

Along with these advances the relative coal consumption has diminished. It was the enormous coal consumption that detracted from the carrying capacity of the *Great Eastern*. It was on that also that Dr Lardner based his famous prediction, when he told the Liverpool merchants in 1838, that a steamer would never be able to carry enough coals to take her across the Atlantic. As a matter of fact they did not for many years, because they economised by spreading sails to favourable winds, and the paddles were made to unship at such times. The coal consumption per horse-power developed was from three to four times that of the present. If a modern liner carries say 3,000 or 4,000 tons of coal in her bunkers for a six days' trip, she would have had to take from 10,000 to 12,000 tons if her boilers were as wasteful as those of the liners in the forties. The steam pressure in the boilers of the *Oceanic* is more than twenty-one times that in the *Britannia*, the engine-power more than thirty-seven times as great, the coal consumption only nine times greater, her passenger capacity eighteen and a half times as great, her tonnage fourteen and a half times as great.

Yet these advances in propelling power, steam generating, and economy of fuel would have been of little use apart from the improvements which have been effected in the hulls of the liners.

For the first ten years or so of ocean steam navigation all the hulls were built of wood. There was one notable exception, Brunel's *Great Britain*, built of iron in 1843. But she was not successful. The Cunard Co. built no ships of iron until 1856, when the *Persia*, the twenty-eighth ship of that fleet, was constructed of that material, though the Inman Co. had built the *City of Glasgow* of iron in 1850.

The wooden hulls were tried severely by the paddles, and by the vibration of the engines. Had they survived until the present time, the construction of the greyhounds could never have been carried out. They would have been broken to pieces by the forces of the engines and revolving screw.

Nor is this all; as long as wood was retained, safety in the event of collision was impossible. A wooden ship could not be made with really safe watertight compartments, though this construction was attempted in the *Royal William*. Since the introduction of iron, vessels have been built with two skins—double vessels—a ship within a ship. The early iron steamships were constructed with watertight bulkheads, but they were neither so large, nor so minutely subdivided, nor carried up so high as they are at present. Moreover, the single screw shaft running aft down the centre of the ship was an element of weakness. It was not until the introduction of twin screws in 1888 on the *City of New York* that fore and aft mid-line bulkheads could be employed. In the big ships now, a space of about 4 feet is left between the inner and outer skin at the bottom.

The use of iron permitted of the building of larger vessels, with better sailing power than those of wood. The introduction of steel permitted the construction of still larger vessels, until now several of the latest of these exceed 700 feet in length, more than an eighth of a mile. Iron steamships are not built now excepting to the extent of about 1 per cent., those being trawlers. Steel is fully 25 per cent. stronger than iron, which represents either added strength or reduced dimensions for equal

strength;—in either case a clear gain. Lessening of weight saves cost of propulsion; lightening dimensions increases carrying capacity by reducing the dead load of vessels, to obtain more room for cargo and passengers, and secure also higher speeds without the sacrifice of any other conditions. The employment of steel, therefore, has been a clear gain.

Although the skeleton of a big vessel on the stocks has a very light and airy appearance when viewed from a considerable distance, the aggregate weight is enormous, and the mechanical difficulties to be faced in construction are vastly greater than those connected with the building of wooden ships. Not many years ago all ship-work had to be riveted by hand. Now a large portion is effected by portable machines.

Besides strength, stability, safety, and speed, the maximum capacity, steadiness of running, and the comfort of passengers are important factors in the problem of the design of a liner. In order to ensure the maximum cubic capacity, and the convenience and comfort of passengers, liners have a section nearly rectangular amidships, which section is continued also along the greater portion of the length of the vessel. This ensures roomy cabins and saloons, while leaving sufficient capacity for engines and cargo; for a big liner has to carry from 2,000 to 4,000 tons of cargo in addition to her machinery and coal. The maximum steadiness desirable is ensured by the great length, from 500 to 700 feet, which diminishes pitching, by the breadth—55 to 60 feet—and by the use of supplementary keels, termed bilge keels, running parallel with the keel proper, and at some distance away, which lessens rolling. And the saloons, state rooms, and cabins are placed centrally where the effects of pitching are least felt. They are also on the upper decks, where there is no risk of flooding.

Since the aim in designing liners is to secure as much speed as possible consistently with adequate capacity for cargo and passengers, the vessel is a compromise, since increasing capacity means, other conditions remaining the same, increasing length, width, and depth, and displacement; adding too to the stresses and strains to which the structure is subjected, and rendering necessary greater propelling power. Yet the dimensions must not be permitted to exceed the capacities of docks, harbours, and waterways, which for the time being may have to be occupied by the vessel. With the growth of liners, however, dock accommodation has to be increased. The docks at Liverpool owe their greatest developments to the Atlantic liners, so do those at Southampton, which has the largest graving dock in the world, being 800 feet long, 110 feet wide, and 27 feet deep at low-water neap tides. With its quay space it covers an area of nearly 50 acres.

The ordinary observer seeing a vessel on her native element, would seldom think of her as a piece of engineering design in a similar sense to that, say, of an iron or steel bridge. Nevertheless she has to be designed by the same principles as bridges, and other girder, or beam-like structures. And the task of designing the hull of a long steamer is not so simple a matter as that of a quiescent structure rooted in firm foundations. The vessel may be nearly suspended midway on the top of a huge roller one moment, and in the next be hung by her ends on wave crests, with the midships but slightly supported over the trough of the sea. In each the tendency is either to bend, or break her back. Huge tidal waves will break with the force of hundreds of tons against the sides of the hull, which impact has to be resisted by the plates, and the huge ribs upon which the plates are built. Or the waves may break sheer over and pound heavily upon the arched deck, swamping cabins, and boiler, and engine rooms, and sweeping away winches and boats, and twisting davits like wire. The stability of the ship, acting contrary to the forces tending to capsize her—her self-righting capacity, which must increase with increased departure from the perpendicular—also have to be embodied in her construction. Neither may a vessel be made too heavy, since that involves deeper displacement and greater engine-power for propulsion.

The strength of design, therefore, which is necessary to withstand forces that change momentarily, and which do not admit of more than approximate calculation, could never have been estimated *ab initio*. Experience has been the great teacher, and only very slowly has it

been found safe to effect modifications upon pre-existing designs. That is one reason why the dimensions and designs of vessels have been so slowly evolved, and why liners of the various companies differ so slightly in regard to proportions of length, breadth, and depth.

The engines and machinery of steamships will be found treated under numerous separate appropriate headings.

Atmosphere (Gr. *atmos*, vapour, and *sphaira*, a sphere) is the general term applied to the whole gaseous portion of this earth. It is perhaps hardly necessary to point out its vast importance to us in sustaining all forms of life, in modifying the heat of the sun, causing the gradual change of day into night and night into day, assisting in the disintegration of rocks and consequent formation of soils, presenting a medium for the transmission of speech and all forms of sound, and so on.

The height to which the atmosphere extends is still an unsettled question, and from its very nature must remain so. In an extremely rarefied state it may even extend to the moon. Wollaston (1766-1828) estimated the height of the atmosphere as 45 miles, at which height it would be about 25,000 times rarer than at the sea level. But even at a height of 6 miles above the earth's surface it is scarcely possible to breathe. Half the density of the atmosphere would be gone 2·7 miles above the earth's surface; half of the remaining density another 2·7 miles up, and so on. Mathematically speaking, the atmosphere would therefore be non-existent on reaching an altitude of less than 100 miles. Yet Liais, from his observations at Rio de Janeiro on the twilight arc, proved that some atmosphere must exist 200 miles up.

The early Greek philosophers were aware that the air was not only a material substance, but that it could be rarefied, compressed, possessed weight and exerted pressure. But exactly what pressure the atmosphere did exert was undecided till the days of Torricelli. The peculiar fact that water refused to rise higher than about 32 feet in a pump had, up to then, baffled philosophers, and it was this great Italian who first showed that it was balanced by the pressure of the atmosphere. The discovery of this fact naturally led to the use of mercury as a measure of air pressure and to the invention of the mercurial Barometer. As a column of mercury 30 inches high is balanced by the atmosphere, and as the weight of this column of mercury equals 14·73 lb., this quantity represents the pressure of the atmosphere on a square inch of surface. To this pressure all bodies, animate or inanimate, are subject, and by calculating the number of square inches on the surface of the body of a man of ordinary stature and multiplying the number by 14·73, we may estimate the air pressure on the human body. This works out to no less than 14 tons. The reason why he is not crushed beneath so enormous a load is that the air and fluids within the body balance the air pressure outside. Any considerable alteration in the amount of pressure exerted by the atmosphere would produce serious results in the human body. When aeronauts reach the higher regions of the atmosphere, the decreasing pressure on the body causes the blood to burst through the delicate vessels in the nose, mouth, and eyes. Similarly, fishes which live at great depths in the sea are destroyed when drawn up to the surface and the hydrostatic pressure is removed.

Chemically considered, the atmosphere is a mechanical mixture of oxygen, nitrogen, and argon, with lesser and varying quantities of carbon dioxide, aqueous vapour, ozone, ammonia, nitric and sulphuric acids, the three "new" gases — neon, krypton, xenon, and traces of helium. One hundred parts of air by volume contain 78 parts of nitrogen, 21 of oxygen, and 1 of argon. The following reasons conduce to show that air is a mechanical mixture rather than a chemical compound—(*a*) The proportions of each element in air are not those of their combining weights (*see* the Laws of Chemical Action under **Action, Chemical**); (*b*) when the two constituents are mixed there is no change of temperature, volume, or any other characteristic indication of chemical action; (*c*) the constituents can be separated by mechanical means; (*d*) in a compound gas the refractive power is greater or less than the mean refractive power of the constituents, but the refractive power of air is the mean of the refractive powers of the constituents; (*e*) air,

driven out of water by boiling, contains an excessive proportion of oxygen due to the greater solubility of that gas in water, but if air were a compound the proportions would remain constant both before and after solution. Oxygen is remarkable for its active properties; it promotes combustion, respiration, and other changes with great energy. Nitrogen, on the contrary, is inert, it supports neither respiration nor combustion, and its chief use in the atmosphere appears to be to dilute the oxygen.

Combustion, respiration, fermentation, and putrefaction all produce carbon dioxide. The amount, however, is very small—but 4 volumes in 10,000 volumes of air. In dry winds and foggy weather, as many as 9 volumes of CO_2 in 10,000 of air have been observed. Then, too, the proportion is greater in winter than in summer, and in the air of cities than in that of the country. The constant formation of CO_2 and consequent diminution of the amount of oxygen is compensated for by the power possessed by the vegetable world of decomposing the dioxide, retaining the carbon and freeing the oxygen.

Aqueous vapour is always present in the atmosphere to the amount of ·4 to 1·6 per cent., varying according to wind, temperature, locality, &c. The hygrometer, by the evaporation of water absorbed by muslin surrounding the bulb of a thermometer, gives an indication of the dryness or humidity of the atmosphere. Ozone is present in minute quantities (1 in 700,000 volumes). Owing to its energetic oxidising properties, it is valuable in destroying unwholesome matter. By the application of pressure it has been liquefied at $-23°$ Cent. Nitric acid is especially noticeable after thunderstorms, and is apparently due to electrical discharges. In 1,000,000 parts of rain water collected in the country, ·5 part of nitric acid was found, but in Glasgow the proportion was 2·4 parts, so that combustion and organic decay may also be regarded as sources of nitric acid. Examination of the rain water of cities proves also that the air of towns contains a larger proportion of ammonia than that of the country. While observation in country districts revealed a proportion of ·9 to 1·1 parts of ammonia in 1,000,000 parts of water, tests made in the large towns revealed as high a proportion as 3·4 in London, 5·3 in Liverpool, 6·4 in Manchester, and 9·1 in Glasgow.

A knowledge of the properties of air is essential to the engineer. The following are the principal, respecting which information will be found under numerous heads in these volumes.

The volume of air required for the combustion of fuel in the furnaces of steam boilers has to be regulated to produce greater or less intensity of combustion. There is no difference in the total heat generated from a given fuel in any circumstances, but the rapidity of such generation is affected by the supply of air, provided the fuel is fully burned. But if insufficient air is admitted, the combustion will not be complete, and the total heat units latent in a given fuel will not be liberated. On the other hand, if the air admitted is in excess, though the fuel may be completely consumed, waste occurs, because too large a quantity of the heat generated is wasted in heating the excess of air to the temperature of the escaping gas.

A cubic foot of air at 60° Fahr. at atmospheric pressure at sea level weighs 536 grains; so that 13·06 cubic feet weigh 1 lb.

Air behaves like a perfect gas, expanding and contracting by equal amounts with each degree of variation in temperature. For any temperature under 30 inches of barometric pressure its weight and volume may be ascertained thus, within less than half of 1 per cent.—

$$W = \frac{40}{T}$$

$$V = \frac{T}{40}$$

Where W = the weight in pounds of 1 cubic foot, V = the volume in cubic feet, per pound, and T = absolute temperature or t + 460° Fahr.

The following formulæ are nearly exact for any condition of temperature and pressure—

$$W = 2{\cdot}71\frac{p}{T}$$

$$V = \frac{T}{2{\cdot}71p}$$

$$t = 2{\cdot}71Vp - 460$$

2·71 = the coefficient for air, and p = the pressure above absolute vacuum.

The hygrometric condition of air is of much importance when questions of ventilation and heating arise. The actual humidity of any sample of air denotes the actual weight of water vapour present in a given volume. This varies greatly with temperature. As temperature rises, the capacity of the air for carrying off moisture increases rapidly. Thus its capacity for moisture is four times as great at 72° as it is at 32°.

The hygrometric capacity of air is utilised in drying and seasoning timber for various purposes, as veneers, staves for coopers' use, the air being heated previously to its introduction to the vessel or chamber in which the timber is arranged. Air drying is also practised in brick manufacture, in leather, glass, paper, fabrics, and many other industries.

Of the impurities present in air, carbonic acid gas is the principal; very minute quantities of ammonia, sulphuretted hydrogen, and sulphurous acid gas are also present. Carbonic acid interferes with the full union of the oxygen of the air with the carbon of the blood. From 6 to 7 parts of CO_2 to 10,000 parts of air is the maximum amount which should be considered permissible in factories. In badly vitiated atmospheres it runs up to from 20 to 40 parts per 10,000 of air. This aspect of the subject will be found treated in the ventilation of factories.

Air, like other fluids, loses head or pressure in its passage through pipes. *See* **Air Friction**. This has to be taken account of when long lengths of pipe are used, though it may be neglected in short lengths.

Atmospheric Engine.—The germ of the modern steam engine, due to Newcomen, so named because the pressure of the atmosphere was utilised to produce the descent of the piston. A brief notice will be found under **Beam Engine, Steam Engine.**

Atmospheric Hammer.—*See* **Pneumatic Hammer.**

Atmospheric Line.—The line on an indicator diagram which separates the steam and vacuum areas. *See* **Indicator Diagram.**

Atmospheric Pump.—The common **Lift Pump.**

Atmospheric Railway. — Though there are no atmospheric railways now in existence for the carrying of passengers, this form of propulsion must always possess an interest from the fact that several such railways were in existence in the forties and fifties. They were constructed on the vacuum system, by the exhaustion of air from a tube on one side of a piston, and the admission of air at atmospheric pressure on the other side.

The first suggestion of this kind came from Mr G. Medhurst, in 1810, who proposed to propel trains in a tube not by creating a vacuum, but by a pressure of something under 30 lb. to the square foot, which he estimated would propel a train at 50 miles an hour, and require an 180 HP. engine. In 1824 John Vallance took out a patent for propulsion by the creation of a vacuum. In 1861 the vacuum pressure system was adopted for the pneumatic postal despatch, being first tried experimentally in Battersea Fields. In 1863 the system was installed between Euston and the Holborn Post Office, a distance of about a mile and a half. The tube was of a ◠ shape, measuring 5 feet in width, by 4 feet in height. In 1827 John Hague took out a patent for propulsion by creating a partial vacuum by means of exhausting pumps, and carrying a line from the pumps to the place where the power was required to be used, and there working a steam engine by vacuum and pressure on the opposite sides of the piston. In 1839 Samuel Clegg patented the atmospheric railway system, and in 1840 an experimental length of line was laid down at Wormwood Scrubbs. In 1842 it was tried on the Kingston and Dalkey line, where it continued working until 1855. It was used on the Croydon line from 1845 for a short period only. It was also adopted at St Germain, in France.

But the principal interest in the atmospheric railway centres around the South Devon line, where the experiment was tried on the recommendation of Brunel, who hoped by this means to get rid of the weight of the locomotive. The line was laid down in 1846 to nearly the whole distance from Exeter to Newton, a distance of 20 miles. There were eight pumping engines in this distance, which were the source

of much trouble, and the curious result was that locomotives had sometimes to be used. Then the leather valves of the tubes caused difficulties, so that trains remained at a standstill, while the engine for the suction was pumping in the vain endeavour to create a vacuum. Exactly four years after Brunel had recommended the adoption of the system, its abandonment was resolved on, and locomotives were used after the 9th of September 1848.

Briefly the mechanical details of the railway were these:—A continuous cast-iron tube was laid on the sleepers between the rails, having along the top, a slit which was covered with a flap valve of leather, stiffened with iron plates on top and bottom faces. It was hinged on one side, so that it appeared like a continuous piece of belt. With the valve close and the pumps exhausting, a vacuum would be produced in the tube. A piston occupied the tube and was provided with an arm which came up through the slit, and was attached to the leading carriage of the train. To permit of this connection the valve was lifted by rollers at the rear of the piston, so allowing the connecting arm to pass, and permitting the atmospheric pressure to come on the piston in the rear, in opposition to the vacuum at the front, the amount of pressure being from about 8 to 10 lb. per square inch.

So far no difficulty was experienced. But trouble arose by the imperfect closing of the valve behind the piston. A roller was used to press the valve down, and the seating surface was lubricated with beeswax and tallow, softened by a charcoal heater, about 5 feet in length, running along with the carriage, which had pressed the valve down. Then the valve had to be protected by a sloping sheet-iron cover, also hinged to guard it from sun and rain. No less than seventeen patents dealing with these valves were taken out during the years 1844 and 1845.

Other valves again were required to enable the train to pass from one section to another. These were hinged, each in a box below, communicating with the atmosphere, and which contained a piston valve of slightly greater area than the one above in the tube, being sufficient to keep the latter closed. The movement of the approaching train opened a slide valve which caused the atmospheric pressure to be taken off the piston valve in the box, so causing it to fall, and by its hinging to the valve in the tube made the latter fall clear of the advancing piston. Five minutes were usually wasted in exhausting a section of about 3 miles. On the Dalkey and Kingston line, which was about 1¾ miles long, the wetness of the leather valve, the result of the condensation due to the exhaustion of air, always made a tight joint. There was no covering plate to the valve as in the Devon system.

For the modern applications of the principle, *see* **Pneumatic Tubes**.

Atom.—As far back as the days of the ancient philosophers speculation was rife as to the nature of the ultimate particles of matter. One school maintained that every particle, no matter how minute, could be divided and subdivided *ad infinitum*; opposed to this was the theory that matter was composed of certain indivisible particles called atoms. (Hence the derivation of the word from Gr. *a*, not, and *temno*, to cut, signifying that which cannot be cut.) Five hundred years before Christ, Leucippus advanced his atomic theory, and was followed by Democritus, Epicurus, and Lucretius. No proof or experimental evidence to support this theory was forthcoming, however, until the early years of the last century. Dalton then revived the theory as the only means of explaining the manner in which carbon and hydrogen combined to form olefiant gas and marsh gas. He found (1804-7), that in olefiant gas the relation of the carbon to hydrogen was as 6 : 1, while in marsh gas it was as 6 : 2. Olefiant gas he assumed to be a combination of 1 atom of carbon and 1 atom of hydrogen, while marsh gas would then be a combination of 1 atom of carbon and 2 atoms of hydrogen; the atom of carbon being 6 times the weight of an atom of hydrogen, whose atomic weight was assumed to be unity. Similarly, with the two oxides of carbon, he showed that the amount of oxygen in carbon dioxide was just double the quantity contained in the monoxide; in other words, CO contained 1 atom of carbon and 1 atom of oxygen, while CO_2 contained 1 atom of carbon and 2 atoms of oxygen.

The oxides of nitrogen provide an excellent illustration of these "combining proportions."

Parts of N.	Parts of O.	
28	15·96	= Nitrous Oxide, N_2O.
28	31·92	= Nitric Oxide, N_2O_2.
28	47·88	= Nitrogen Trioxide, N_2O_3.
28	63·84	= Nitric Peroxide, N_2O_4.
28	79·80	= Nitrogen Pentoxide, N_2O_5.

Nitrous Oxide is thus regarded as being composed of 2 atoms of nitrogen and 1 atom of oxygen; each of the nitrogen atoms weighing 14 as compared with 15·96 for the atom of oxygen. Then if the theory were sound there could exist no other compound of nitrogen and oxygen in which the relative weights of the two elements were not multiples of 14 and 15·96, for an atom is indivisible. A glance at the table shows this to be the case. Nitric Oxide is found to contain 31·92 parts by weight of oxygen in proportion to the 28 of nitrogen. Now 31·92 equals $15·96 \times 2$. Similarly in Nitrogen Trioxide $47·88 = 15·96 \times 3$; in the Peroxide $63·84 = 15·96 \times 4$; in the Pentoxide $79·80 = 15·96 \times 5$. Thus the series of oxides is regarded as being formed by the addition of another atom of oxygen to the preceding oxide.

Dalton also allotted to each element an atomic weight, that is, the relative weight of an atom compared with an atom of hydrogen. The latter he took as 1, because he found that it entered into combination with a smaller proportional weight than any other element. The atomic weight of oxygen he set down as 7·98, for he discovered that water was formed when the same weight of hydrogen which had combined with the atom of carbon to form olefiant gas was combined with oxygen. The atomic weight of nitrogen was represented as 4·66; carbon, 6. These, and many others, proved subsequently to be incorrect, while even at the present time we can scarcely regard the atomic weights of some of the elements as absolutely correct, for in many cases alternative ratios may be accepted. In certain cases, notably in that of oxygen and nitrogen, the atomic weight has only been adopted after nice experiment or delicate reasoning. Dulong and Petit, by the discovery of the law that the atoms of nearly all elements have the same capacity for heat, greatly assisted the accurate fixing of the atomic weights of the elements. Their experiments showed that the specific heat of an element multiplied by its atomic weight produced a constant quantity, 6·4. Thus:—

$$\text{Atomic weight} = \frac{6·4}{\text{sp. heat}}$$

It need scarcely be pointed out how valuable this method of checking atomic weights has proved in cases where doubt has existed as to which of two or three values should be adopted.

During recent years, however, physicists have come to regard the atom in a different light. It is no longer considered as the ultimate form of matter, but as a (comparatively) huge, hollow globe containing countless "electrons" or "corpuscles" in motion. These corpuscles are charged with negative electricity, but as they would thus repel one another they must be considered as being surrounded by a sphere of positive electrification.

Atomiser.—In the burning of liquid fuel the most usual method is to reduce the liquid to fine particles by the agency of steam, or of air, or by kinetic energy. The instrument by which this reduction is effected is known as an Atomiser.

The object of atomisation is to reduce the liquid fuel into particles of an infinitesimally small diameter, and to surround each particle with sufficient air to burn the particle perfectly. Thus an atomised stream of liquid fuel may be said to be in the form of a vapour loaded with particles of small size floating in an atmosphere, and only requiring to be ignited for combination at once to ensue.

The arrangement of an atomiser is rather a part of furnace design, but it has been said that atomisers must be of such size as not to supply too much fuel within a given space, but so as to fill the whole breadth of a furnace with vapour of uniform richness duly mixed with air and supplied from below with such further air as may be found necessary to perfect combination. In order thoroughly to understand what is the duty demanded from an atomiser, it is necessary to discover what is the actual value in foot pounds of the work it has to perform.

All liquids possess a property of surface tension which is a measure of the cohesion of

its molecules. When a liquid is divided into separate and independent parts, the work of division may be stated in foot pounds.

In bulk, liquid fuel, or as it will hereafter be called, oil, has little or no surface relatively to bulk. When atomised, its surface is considerable. Ordinary petroleum has a bulk of 30 cubic inches to the pound with a density of 0·92, according to the U.S. Bureau of Steam Engineering. The surface of 1 lb. of oil in spherical drops is $(180 \div d)$ square inches when d is the diameter of the particles in fractions of an inch. To stretch a petroleum surface requires 0·0000151 foot pound per square inch, whence is deduced the work of atomisation $W = 0{\cdot}00272 \div d$ foot pound per pound of oil, or where $d = 0{\cdot}0001$ inch, then $W = 27{\cdot}2$ foot pounds per pound. A gravity drop of oil has a diameter of about 0·15 inch, and in order to spray oil by centrifugal action the expression $n^2Dd = 10{,}570$ is first given, where n = revolutions of centrifugal disc per minute, D = disc diameter, and d = diameter of spray drops in inches. The kinetic energy represented by this value for oil of ·92 density will be $0{\cdot}00311\frac{D}{d}$ foot pound per pound of oil, which, added to the surface stretching work, is $\frac{0{\cdot}00272 + 0{\cdot}00311D}{d}$ foot pound per pound of oil. The kinetic energy is 1·14D times the energy to overcome the surface tension. Then an 8-inch disc throwing drops of 0·0001 inch will absorb 27·2 foot pounds in surface stretching, and 248·8 foot pounds of kinetic energy or 2·76 foot pounds per pound total. When sprayed by a steam jet a good result is 0·5 lb. steam per 1 lb. of oil, and in a moderate steam engine 28,700 foot pounds of work are done by 0·5 lb. of steam. If this power were put into disc rotation it would spray 104 lb. of oil into drops of 0·0001 inch diameter. Hence the desire to find a good centrifugal atomiser which would only use 1 per cent. of the steam used by a steam-worked spray atomiser.

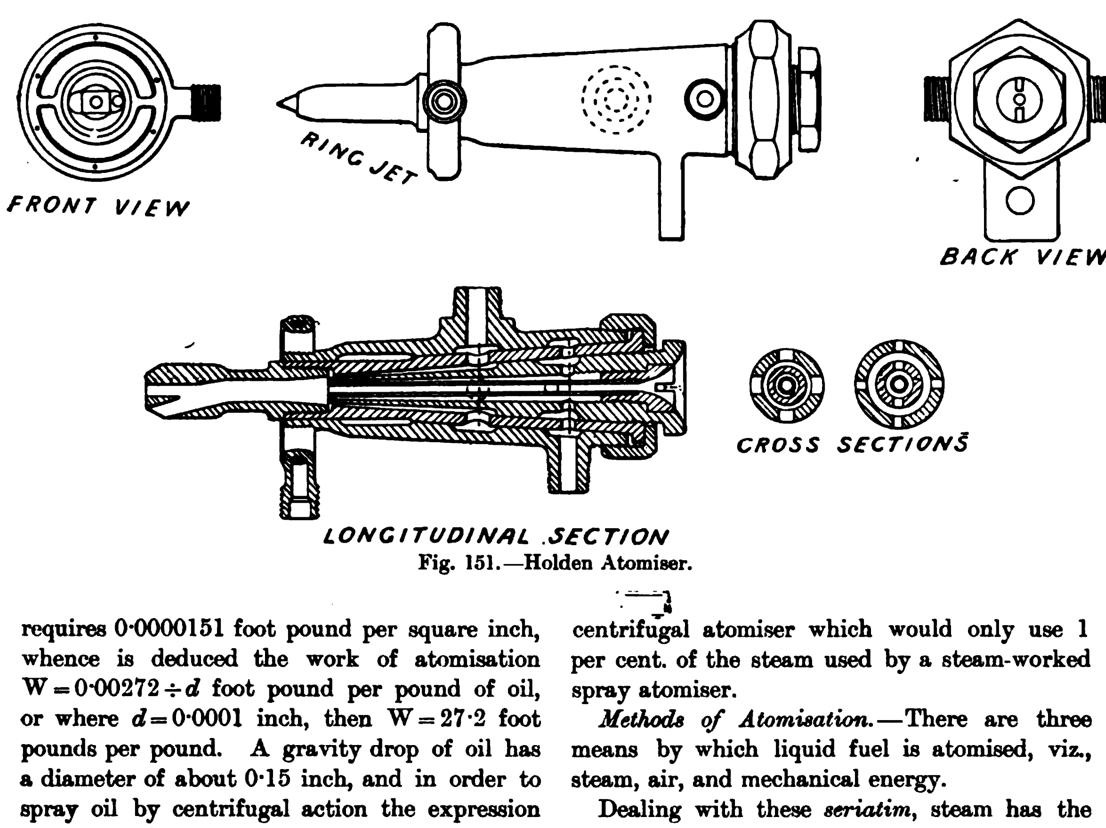


Fig. 151.—Holden Atomiser.

Methods of Atomisation.—There are three means by which liquid fuel is atomised, viz., steam, air, and mechanical energy.

Dealing with these *seriatim*, steam has the advantage that it is a fluid generated in the boilers to which the atomised fuel is applied, and no special mechanism is called for. It is claimed also that when steam is employed as the atomising agent the resulting combustion is more perfect than when air alone is employed. The contrary view was held by M. Bertin in the first edition of his book on water-tube boilers, but he modified his views

in the second edition, and no longer upheld air atomisation as better or more economical than steam. The United States Liquid Fuel Board advise that steam spraying, while best for general land purposes, requires too much make-up water for marine purposes; also that the rate of combustion per unit of space volume is reduced as compared with air atomisation. The steam as well as the oil should be superheated before it reaches the atomiser. Heated oil is much less viscous, and atomises more perfectly than cold oil, and dry steam superheated also ensures safety from water, and better combustion.

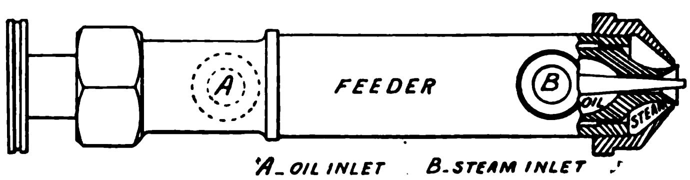


Fig. 152.—Hydroleum System.

Air Atomisation.—As an atomising agent air enables more oil to be burned in a given space than does steam. It should be heated in order to improve its efficiency, and it has the very great advantage that being necessary to combustion, it supplies oxygen to the fuel from the outset. If a certain amount of water vapour is really necessary to complete combustion, there appears no reason why this cannot be added somewhere in the course of the air from the compressor to the burner. The pressure necessary for air atomisation is a matter of wide variation of opinion, a minimum of 15 lb. being given by some engineers, as high as 60 lb. advised by others, and even as low as 1 lb said to be satisfactory with some forms of atomiser.

Mechanical Atomisation.—This has been experimented with as above stated with centrifugal disc atomisers. Since steam has the disadvantage of loss of water, and air that of requiring heavy and bulky machinery for compression, some employ a sprayer jet, the atomisation being effected by the pressure of the oil itself forced in a fine stream at heavy pressure through a spiral jet. The foregoing atomisers will be briefly described and illustrated in the sequel.

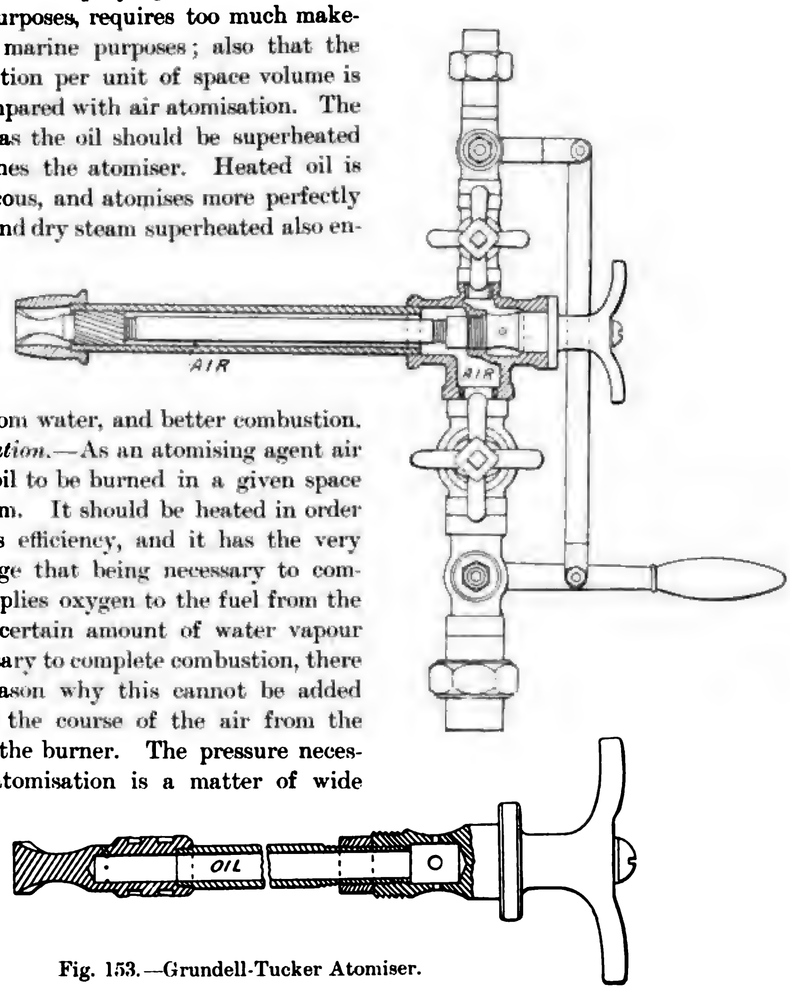


Fig. 153.—Grundell-Tucker Atomiser.

Holden's Atomiser.—This atomiser, Fig. 151,

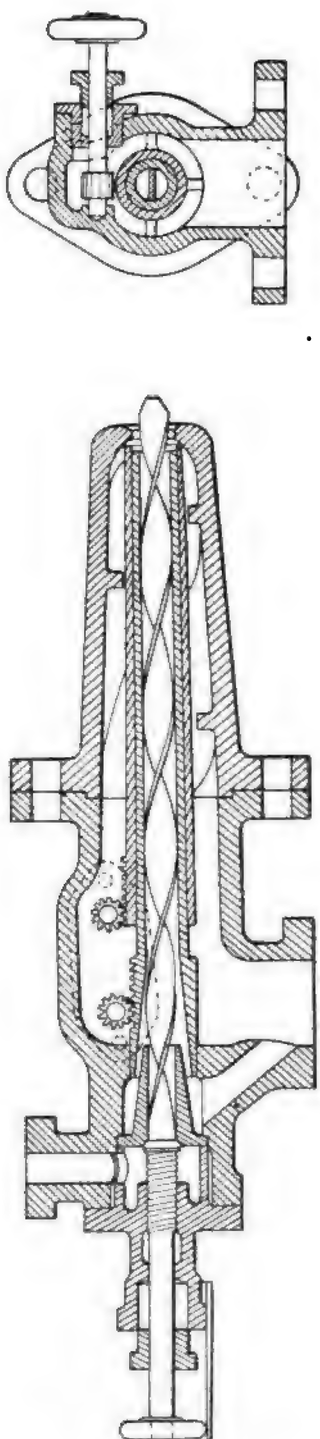


Fig. 154.—Kermode Atomiser.

has been successfully applied to the locomotives of the Great Eastern Railway, two atomisers being employed which direct the oil into the furnace a few inches above the grate, covered with a light fire of coal, and chalk lumps or broken brick. This atomiser is of the injector type. It contains a central air passage surrounded by a narrow annular steam passage, outside which again is an annular oil passage. The mixed jet of air, steam, and oil travel forward to the Y nozzle which sends the jet forward and laterally. A ring of small steam jets focuses upon the nozzle and promotes further spreading, as well as inducing a flow of air through a surrounding hole in the fire-box rail through which the atomiser points. Further air for combustion comes through the light fire on the grate below. Each burner averaged an oil consumption per mile of 6 lb. over a month's run. The whole interior of the atomiser can be drawn out for cleaning without requiring any pipe disconnection. As much as 9 lb. per mile may be passed by each burner.

The Hydroleum System employs a steam atomiser, Fig. 152, with central oil passage and an annular steam orifice with a splayed outlet guide which serves to balloon the flame. But a wall or slab of fire-brick is placed about 18 inches in front of the jet, and considered necessary. These atomisers pass from 1 to 12 gallons of oil or tar per hour, according to size. There would be three atomisers in one horizontal line in an ordinary marine furnace.

The Grundell-Tucker Air Atomiser. — This atomiser, Fig. 153, was used in the S.S. *Mariposa* between San Francisco and Hawaii. Oil is admitted centrally and escapes by small holes spirally drilled in front of the air supply, which issues in a gyratory manner through spiral threads or blades in the air annulus. At the nozzle the mixed jet balloons out. The air was supplied hot at 40 lb. pressure, and each burner appears to have dealt with 125 to 140 lb. of oil per hour. Both oil and air should, it would seem, be supplied at considerable pressure. Not less than 15 lb. per square inch is thought by some to be necessary for the air, but others appear satisfied with only 3 lb., as in the Kermode Atomiser, Fig. 154, while the atomiser of Fig. 155 is stated by the U.S. Liquid Fuel

Report to have been satisfactory with only 1 lb. of air pressure, the flame secured being short. This atomiser has also been satisfactory when used with steam. The oil enters centrally through the needle valve orifice and is introduced as a thin layer to the spirally drilled air jets.

The Mechanical Atomiser.—An example of this type is the Korting Jet, Fig. 156. It is simply a nozzle with an inner screwed needle.

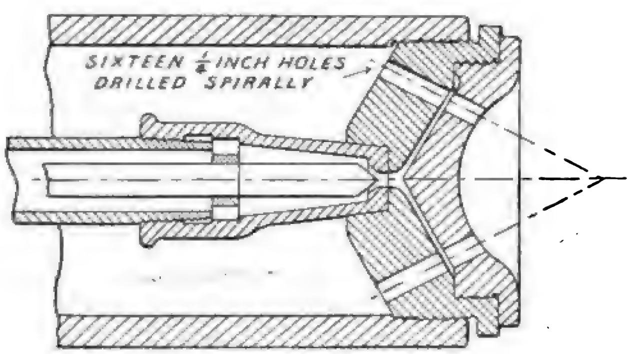


Fig. 155.—Needle Valve Atomiser.

The oil is supplied heated to 194° Fahr., and sprays itself by its rotatory movement acquired in passing the screw under pressure. In the S.S. *F.C. Lacisz* the oil was supplied at 50 lb. pressure and heated to 266° Fahr., though it is said by many experts that there is risk of dissociation above 140° Fahr.

Tests at Cherbourg with 84 lb. pressure showed results as below :—

Orifice -	1 mm.	1 mm. ·25	1 mm. ·5
Oil per hour -	143 lb.	220 lb.	297 lb.

The French Naval Authorities state that these mechanical atomisers work satisfactorily with oil filtered and heated to 176° Fahr.

Obviously if oil will spray itself, the pump necessary to do the work will occupy much less space than an air compressor.

Centrifugal Burners.—As a result of tests on disc centrifugal burners, Mr Williams has designed the centrifugal burner, Fig. 157. The spraying disc is carried by a steam turbine blown by a jet of steam brought from below. The steam escapes to the furnace underneath the disc and induces also an air supply. The oil overflows upon the disc by a central opening, and also by holes round the bore-plate, which enable a continuous stream of oil to pass up also by way of the pivot bearing. Such burners seem most suited to such furnaces or locomotive fire-boxes, in which they would be centrally placed. The difficulties of temperature, &c., suggest themselves, but probably are much reduced by the cooling effect of the oil and steam. It will be seen that no oil can escape to burn under the disc. The lubricating oil must escape over the disc surface.

From the foregoing brief sketch it will be apparent that very diverse designs have been made for atomisers. Some atomisers have a small V-shaped prism point held in front of the issuing jet of oil with the object of spreading it more widely, and other designs have wide flat orifices out of which oil slowly creeps, to be caught by a fine jet of steam from a parallel orifice. These wide sprayers find favour in American locomotive work.

Injector type atomisers are frequently rather noisy, and not therefore suited for work except on a railway, where their roar is concealed in other sounds. The Hydroleum Co. removed the noise by means of a trunk air supply, the trunk being carried outside the wall of the boiler-house, where it appears to carry the sound of the atomiser.

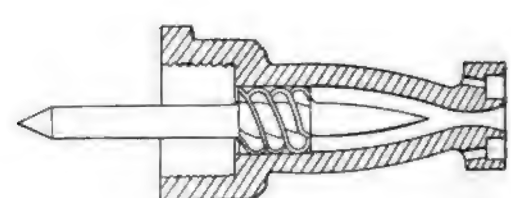


Fig. 156.—Korting Jet.

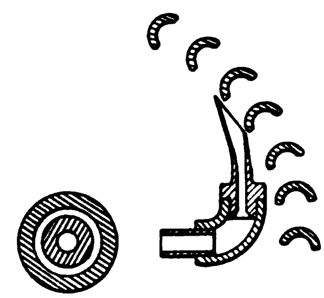
Attwood's Machine.—A machine used in class-room demonstrations to illustrate the accelerated motion of falling bodies under the influence of gravity. It consists of two equal weights, suspended from opposite ends of a cord passing over a pulley, the movement of which is rendered as nearly frictionless as possible, together with means for loading one end of the cord more than the other, and for measuring the times of descent of the heavier end. The

pulley and its supporting friction wheels are carried on top of a steel tube, standing about 2 metres high, with a millimetre scale, and fixed on a heavy tripod with levelling screws. Stages or platforms are adjustable on the tube, and a seconds pendulum is included. The force which produces motion is a weight in the form of a bar laid on one of the equal weights, and by which equilibrium is destroyed, and the weight caused to descend. It acquires a velocity due to one second in reaching the first platform, and passing through that, leaves the loose added weight behind, and passes to the second with the velocity acquired during the first second. The results obtained are approximations only.

Auger.—A boring instrument for wood, of greater length, and generally greater diameter than an ordinary bit. Unless otherwise specified, it is understood to be an instrument fitted with a long handle at right angles to its shank, like a very large gimlet. It has some form of cutter at its end, and its body for some distance back may be either a shell, or twisted, the latter form being better because it requires less skill to bore accurately with it. An auger without a handle, but with a square or round shank intended for use in a brace or in a machine, is generally called an auger bit, or a machine auger. Ordinary twist bits, even of small size, are sometimes called auger bits, because compared with the older form of centre bit they are very long. A tool intended, not for boring holes, but for reducing the diameter of rods and spokes in order to form a tenon on their ends, is called a hollow auger. A similar tool for tapering the ends of rods is called a taper auger.

Augers are very numerous. The commonest are magnified gimlets, both of the shell, and the twisted form. The shell auger lacks power of entrance, so that its hole must generally be started by means of a centre bit, or by exercising great pressure on the auger. But in the latter case there is difficulty in ensuring exact centring, which is assured by preliminary boring with the centre bit. The screw auger, however, starts well.

With regard to the form of the shank, this is very much a matter of opinion. The shell, or



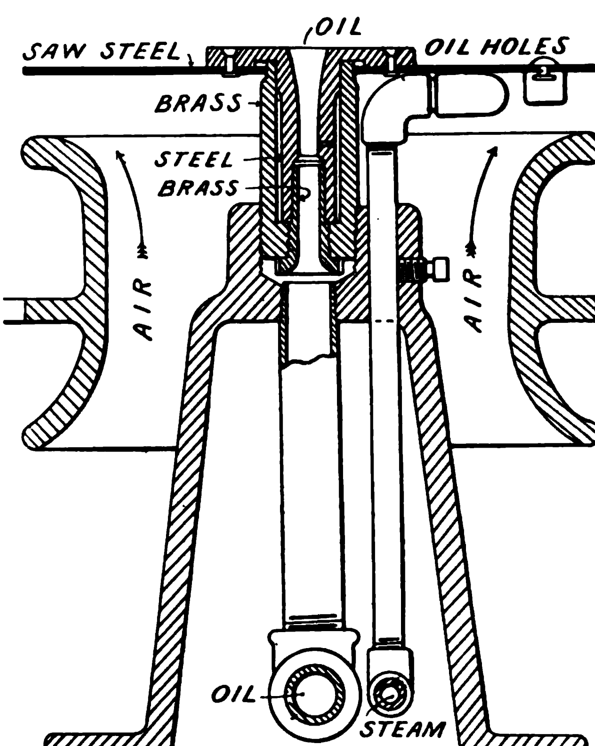


Fig. 157.—Williams' Centrifugal Burner.

"pod," cuts a fairly clean hole, but the "core" of wood cuttings does not find its way out of a shell, so that the auger has to be removed at every few inches to draw the cuttings out. The twisted form draws the cuttings out (in theory), but unless the tool is withdrawn occasionally, the friction is very severe.

But neither of these are the best possible forms, though still perhaps the commonest. Better tools are those designed on the models of the screw bits, of Gilpin's, and Jennings types, the principal features of which lie in the double or balanced cutting of the lips, the inclusion of nickers, the very large clearances left in the spirals, and the longitudinal clearances.

It must, however, be clearly understood that no one auger is the best possible for boring alike in hard and soft woods, in their infinite range of variety, and for boring in end grain, plank way of the grain at an angle, and straight, and producing clean holes in all. It is no more possible to have a universal auger than a universal turning or boring tool. The following remarks, therefore, have reference to the principal kinds of augers used, and their special utilities or features of value.

Fig. 158, A, shows the common shell auger, and B the screw auger. Both of these are fitted either by means of a tang, or an eye, the latter being the stiffer job. A variation in the shell auger is the taper-shell C, used by ladder makers for boring the tapered holes for the rungs.

The first departure to be noted is the suppression of the screw point in some cases, as in the well-known ship auger D. It is held that the presence of a screw in any auger causes the tool to follow the grain or shakes, or to be diverted by knots. This is true in a slight degree. But the screw is so valuable in starting a hole to a centre, that it is retained on most bits, and good guidance is ensured in other ways, either by having one nicker or lip, or two. These, by flanking the screw, and entering and cutting just immediately after the screw, practically coerce, and prevent any risk of the latter being drawn to one side. A bit of the single nicker kind,—the Ford, is shown at E, and one of the double,—the Jennings, at F. The only possible objection to these bits is that

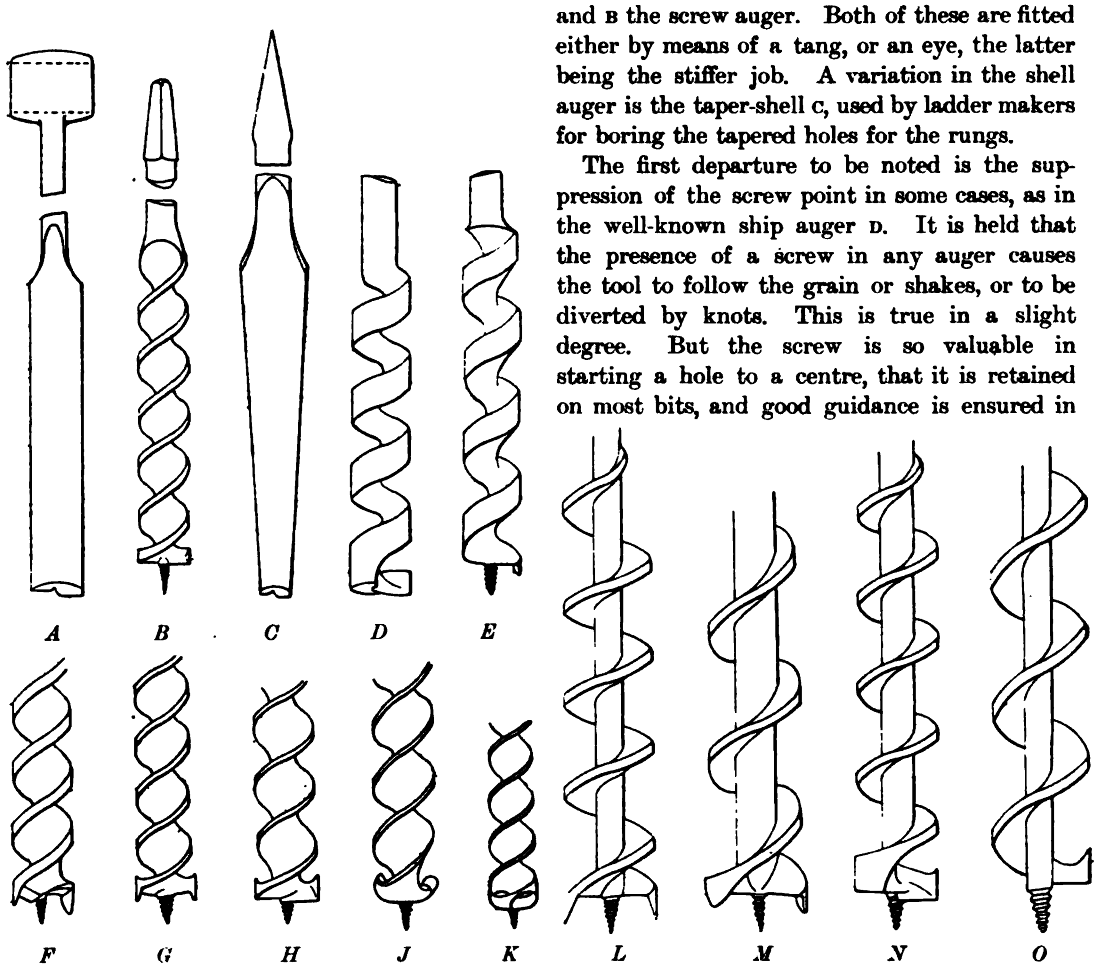


Fig. 158.—Forms of Augers.

A. Shell type. *B*. Screw ditto. *C*. Taper-shell. *D*. Ship auger. *E*. Ford type. *F*. Jennings ditto. *G*. Double spur auger. *H*. Ditto. *J*. Gedge forms. *K*. Solid nose.

the lips are liable to become damaged by contact with nails, grit, hard knots, and legitimate wear. But the bits are still in the same condition as those made without nickers, and so can be retained in service.

The double spur auger G is by some considered superior to the single. In another form the single spurs are carried backwards, H. These are used by carpenters, and wagon builders. They are supposed to increase guidance, and to be more durable than others.

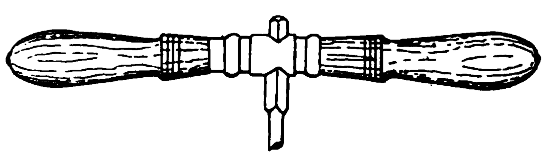


Fig. 159.—Auger Handle.

They answer well in both hard, and sappy woods, and in deep holes.

Next come the augers with both screws and curved lips — the Gedge type, J, and K, the solid nose variety. These bore very sweetly, but the lips are rather delicate, and if they break, the augers are spoiled.

An important detail is the formation of the screw shank. These are varied in being single, or double, the double twist being able to carry away the chips more freely than the other. Another difference is that due to the manner in which the screw is produced. The double twist is not so well suited for boring straight holes as the single. The screw in both is formed by twisting the steel into the shape. Hence the web or the metal about the axis is weak, just as it was in the earlier style of twist drills, similarly formed. An improvement, therefore, on this style is the forged augers of the Irwin type, L to O. In these the shank is circular in transverse section, and is therefore very stiff, and the screw makes a single turn round it exactly like the common conveyor screw. It is thus the stiffest auger made. In the form of its lips it follows the usual patterns, being made with single and double lips, lips facing downwards, and upwards, and with convex forms.

The method of making the twist in augers has some effect on friction. The object should be to keep the chips away from contact with the sides of the hole being bored. This has been carried to perfection in the Ford bits, E, where the chips are forced inwards by the twist towards the centre. All these forms occur in the regular auger, with cross handle, and in the bit style, or auger bit, with square tapered tangs for use in the bit stock. Another class is the machine augers for use in the auger boring machines. The same forms are mostly retained in these, but the tang is of circular section. Fig. 159 shows an auger handle.

Hollow augers, Fig. 160, are used for cutting circular pins, tenons, dowels. Their knives are adjustable, so that a range of sizes, usually from $\frac{1}{4}$ or $\frac{3}{8}$ to $1\frac{1}{2}$, can be cut. Some are fitted with depth gauges.

Another group of augers is that used for well-boring. Small diameters can be operated by hand, larger ones must have an auger turning attachment. Different kinds of earth require different tools. Some of the principal forms

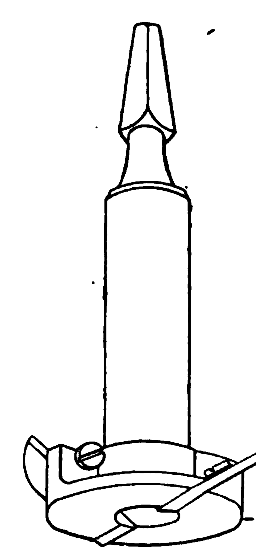


Fig. 160.—Hollow Auger.

are shown in the article **Bore-Holes**. Hand-boring augers, suitable for boring in earth and clay, embody the screw form and lip. These will deal with holes suitable for pipes of from 2 to 6 inch bore. Larger augers have a steel worm, and single-cutting lip. Another has a cast-iron worm and steel lip, but is encased to hold the dirt better. Another is a hinged auger, having two scoops which penetrate among stony and

clayey soils, and bring up the stuff, which is released on the removal of the pin above. Another has a cylindrical body above the steel-cutting edge, which is closed by a door. When opened, the stuff is discharged. These augers are used for holes ranging from 8 to 20 inches.

Auger Bit.—*See* **Auger.**

Auger Board.—*See* **Bore Holes.**

Auger Boring Machines.—The use of these valuable little machines has grown rapidly in engineers' heavy carpentry, saving most of the time occupied in boring bolt holes with hand augers. They take machine augers, which can be operated perpendicularly, or at an angle, the spindle being rotated by means of bevel gears from lever handles, hence the power available for work, which beats the hand tool many times over. The machine is simply laid by its base upon the balk to be bored, and the upright which carries the mechanism for boring is adjusted on its quadrants for vertical or angular work, and lifted to the proper height by the racks, when the boring is commenced.

Austenite.—The term given to the constituents of a high carbon steel when suddenly quenched. It occurs when steel containing 1·5 or 1·6 per cent. of carbon is raised to a high temperature, say 1,000° Cent., and quenched in ice-cold brine or liquid air.

Austrian Bronze.—The material used by the Austro-Hungarian Government for field guns. The compositions of these bronzes are given approximately as follows:—

Copper	-	61·50	to	53·90	per cent.
Zinc	-	35·70	„	40·00	„
Manganese	-	0·60	„	3·75	„
Aluminium	-	0·94	„	1·25	„
Iron	-	1·26	„	2·0	„

The Austrian Authorities have developed these bronzes in preference to using steel, and have probably been able to obtain better results than would be possible with English bronzes. The latter compare well with steel, except in the elastic limit, which is as 15 tons to 28 tons. The Austrian bronzes are readily forged and rolled, and the claim is made, that treated thus, they are equal to the best nickel steel.

Autogenous Soldering. — Denotes the union of metals by simple fusion of the surfaces, without the interposition of solder. Oxy-hydrogen gas is used, the hydrogen being evolved by the action of hydrochloric acid upon zinc shavings, and stored in cylinders. It is directed upon the joint by the blow-pipe. The surfaces to be united must be cleaned. Electric welding is more tractable, and convenient.

Autographic Diagrams.—These are made use of in large numbers of mechanisms, either with a view to eliminate the necessity for attendance, or because an attendant would be unable to make a correct diagram. Varying degrees of pressure, volume, speed, time, stress, and strain are thus recorded. The details of these will be found treated under numerous heads, but particularly *see* **Blast, Indicator Diagram, Speed Recorder, Testing Machines.**

Autographic Recorder.—*See* references under preceding term.

Autographic Testing Machine. — *See* **Testing Machines.**

Automatic Belt Shifting.—*See* **Automatic Reversal.**

Automatic Boiler Feed. — *See* **Boiler Feed.**

Automatic Coupling.—*See* **Coupling.**

Automatic Cut-out.—*See* **Cut-out.**

Automatic Gear - Cutting. — Great advances have taken place in the cutting of gears of different kinds, without the necessity for attention after the first setting, until the teeth are all done. In some machines no supervision is given to the work until the ringing of a bell announces the completion of a wheel. Automatic methods are embodied in different machines for cutting all the ordinary kinds of gears;—spur, bevel, and worm. The difference between the fully automatic and the semi-automatic is that the machine takes charge of the pitching in the former, while in the latter an attendant has to shift an index peg, or turn the dividing mechanism between the cutting of each tooth space.

The automatic gear-cutting machines involve more mechanism than those which require attendance, but their advantages are considerable when small gears are in question. The important point is to have mechanism that cannot by any mischance permit of a second

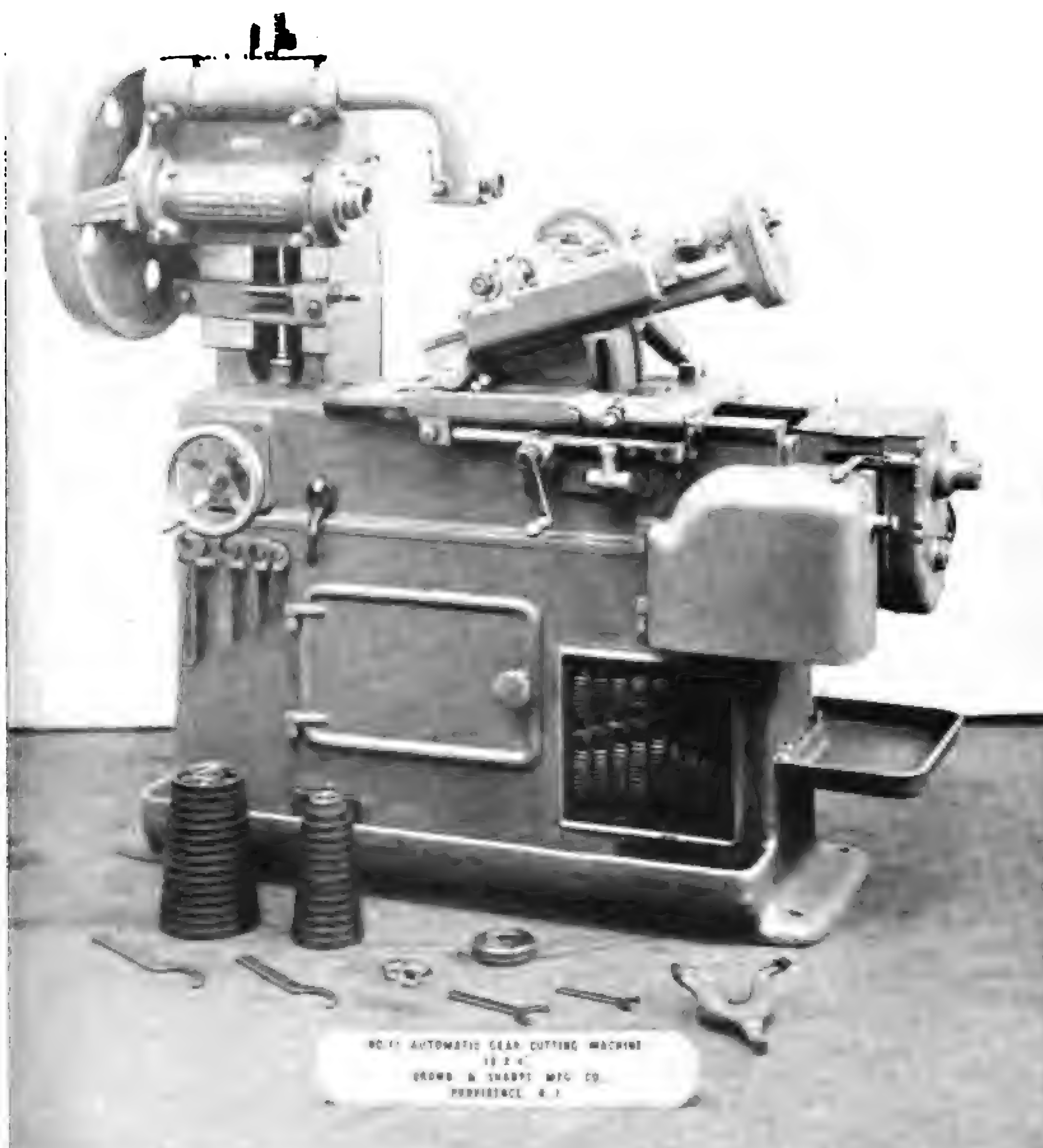


Fig. 161.—Automatic Gear Cutting Machine. (Brown & Sharpe Manufacturing Co.)

To face page 226.

tooth being cut before the preceding one is completed, and that will not pitch incorrectly. This is ensured in various ways in different machines, but it embodies some kind of locking and releasing arrangement, which will be found illustrated in some of the machines selected for description in this work.

The value of the automatic principle lies chiefly in small gears, and those of medium size which are required in quantities. Its value is less perhaps in shops where the machines are numerous, than where only two or three machines are available. If say there are from four to half-a-dozen gear-cutters at work, one man can easily attend to the division plates of all of them. But if there are only one or two, his time is not wholly occupied. In this case a fully automatic machine will prove economical, because it can be started and left running until the wheel or wheels are completed. It is the practice sometimes to run such machines by a small gas engine or motor, and leave them working through the night.

When to the automatic mechanism the multiple cutting is added, the advantages show in a greater degree. This applies to spur gears, as many as from four to six being arranged sometimes on one mandrel to be cut through at a single traverse. Automatic movements are fitted to machines for cutting both spurs and bevels, and to those both of the rotary-cutter, and the planer types. Fig. 161, Plate XIII., is selected as an example of an automatic gear-cutter, for both spurs and bevels. The details of gear-cutters are described under their various heads, but we may point out briefly the means by which the automatic movements are obtained. There are two motions which have to be effected,—the partial revolution of the wheel blank, after the cutting of each tooth, to bring another tooth round to be cut, and the reversal and rapid return of the cutter after each tooth is finished, — ready for another traverse. The first is effected through the large dividing worm seen on the extreme left, driven by a worm through a train of index gears, which are provided to suit the pitching of each wheel required. A portion of a revolution is thus given to the blank, which is then locked. The cutter, with its slide, advances, and commences to operate at a suitable speed. After it has passed through the metal, a trip on the slide throws over a clutch which runs the slide back at a rapid rate. Another spacing then takes place, and the cutter again advances. These operations continue until the full round of teeth have been finished. As this machine cuts bevel gears as well as spurs, the cutter slide has a tilting portion (shown elevated to an angle in the illustration), providing for the various bevels of wheels. Provision is given for varying feeds to suit the cut, and metal.

The leading types of gear-cutters will be illustrated in these volumes. The following remarks indicate the broad lines along which the development of the automatic machines has taken place.

There are many machines which are so far automatic in character that the whole of the flanks facing in one direction are produced without attendance, in others, both flanks are done.

The gears which lend themselves best to fully automatic work are the spurs, because the flanks of the teeth are parallel, and opposite flanks are therefore produced at once by a cutter which is an exact counterpart of their shapes. The only special mechanism then required is that for automatic pitching, locking, and release. The case of bevel wheels is different, because the cross sections of the teeth, and tooth spaces change constantly, and this is a much more difficult problem to deal with than the mere pitching of teeth. Hence until a comparatively recent period, automatic cutting was restricted to spur gears, large numbers of machines for which are in use. Successful semi-automatic bevel gear cutting machines are made, using rotary cutters, and having provision for cutting all one side of the teeth without attention. But the ordinary rotary cutter is being largely displaced by reciprocating planing tools, and by special forms of cutters which are not counterparts of tooth shapes but are instruments for generation, controlled in various ways. These two groups of machine tools are among the most interesting of later developments.

The planer type employs a simple tool which has a narrow cutting edge that is compelled (by different devices) to travel in the path of

the bevel of the tooth towards the apex of the cone of the gear. Its movement in the other direction is controlled by a former, the profile of which is that of the tooth required, but made from three to four times larger (to lessen risk of error). There are several planer machines, some being automatic, most have one arm only, some have two. Being controlled by a former, either cycloidal or involute teeth can be cut.

The generating machines are all automatic in action, but they will only cut involute or single curve gears. In most of these the conjugating principle is involved, that is the essential element is either a forming gear, or mechanism which produces the same effect as a forming gear, in each case the result being that any gears of the same pitch are produced to interchange from a single master element. Thus for example as all gears will mate with a rack, the rack tooth, or an equivalent, is the master gear in this system. The advantage of these types is that any errors due to the use either of rotary cutters or of formers are avoided, since every separate gear is produced by origination, just as a rack tooth might be supposed to develop mating teeth in a semi-plastic substance.

In one type the cutter takes the form of a complete master gear wheel, the teeth of which are generated as by a rack, and which being hardened, ground, and backed off, cuts all other gears of that pitch. In another the section of the cutting tool is that of a rack tooth, in others a mere sharp point or edge. In another a rotary cutter is employed. Not the least interesting part of some of these machines is the mechanism by which the bevels are imparted to wheel teeth. There is a constant change going on in the angle of the gear, or of the shaping arms. In one or two machines also the blank is revolved through a distance equal to the pitch after each cutting stroke, so that at any given angle the whole of the teeth receive a single cut on each flank.

Automatic Governing.—*See* **Governors.**

Automatic Gun.—*See* **Machine Gun.**

Automatic Injector. — A re-starting injector. *See* **Injector.**

Automatic Lifter.—A term which designates a form of lifting mechanism for drop hammers, described under **Brett Lifter.**

Automatic Lift Gates.—This relates to the gates of lifts or hoists which have certain safety arrangements to prevent risk of people falling down the wells. That they are not easily designed is illustrated by the fact that so many devices have been patented and made. The conditions which should be fulfilled are that it should be impossible to open the gates at any floor unless the cage is about level with it, unless a special key is used. Also when opened it should be impossible to move the cage away until the door is closed and fastened. It is also desirable to provide means for controlling the lift from floor, or cage. *See* **Lifts.**

Automatic Lubrication.—The reasons for making lubrication independent of frequent attendance are various.

About the first application of this kind was that of the bearings of line and countershafts. At one time these, without exception, were oiled about once a day, by the crude device of the man in charge ascending a ladder and pouring sufficient oil into the cup to fill the latter to the brim. The oil might then run away into the bearing quickly, or slowly. If the first, it would soon find its way into the tray below, and the bearing would be left to get hot and perhaps seize. If the second, the bearing might become hot through lack of a sufficiency of oil. The services of the oiler were thus incessant, but in spite of that, bearings were always giving trouble and requiring renewals. At present the self-feeding lubricators, using either oil or a semi-solid lubricant, have largely displaced these crude and unsatisfactory methods. *See* **Lubricators.**

In other cases automatic lubrication is adopted either because of the risk, or the practical impossibility of getting at bearings among moving motors and machines, with an oil-can. Or because a supply from such a source would be inadequate. Cases in point are the trough form of lubricators, having brass tubes fitted with taps, brought thence to bearings behind moving rods, or cranks, or behind fixed portions of machinery. All large engines, and many small ones, are fitted with these, so that the attendants need not approach the actual bearings while the engines are in motion. The self-feeding lubricators of shafting are often also

fitted partly for this reason, to avoid the risks of moving about among revolving pulleys and running belts. A third reason is due to the growth of the high-speed enclosed engines. Ordinary lubrication would be wholly insufficient here, hence the working parts are enclosed, and move in a reservoir of oil, generally supplied under pressure, and the automatic lubrication goes on without any further attention during several months. These arrangements will be found illustrated in drawings of high-speed engines.

The necessity for automatic lubrication has developed also in the higher duty demanded of some classes of machine tools, notably of the automatic screw machines, and turret lathes, and some gear-cutting machines. It is found necessary to supply the oil used at a considerable pressure, sometimes very high, in order to conduct the heat away from the tool point and the work with rapidity. In such cases a force pump and distributing pipes form an essential fitting of the machines, so that the lubrication continues as long as the machine runs. *See* **Forced Lubrication, Lubricators.**

Automatic Machinery.—The term automatic is strictly applied to machines which work entirely without human intervention. In a case where only a portion is self-acting, as a lathe slide rest, this does not constitute an automatic machine, because the turner still has to set in motion, and perform several movements, which the lathe would not do of itself. But an **Automatic Screw Machine** is a true case, since it does everything automatically.

The object of automatic machinery is primarily to eliminate labour, the cost of which adds to the expense of manufacturing. But a secondary result is that the product is improved, from the point of uniformity and accuracy, since it does not depend upon the fallible human element. The case for automatic machinery therefore, lies in the repetition of an operation, or several operations, which go to make up a process. It may be a simple repetition of a mechanical act, as stoking, or a more complex operation, as stamping, bending, cutting, &c., performed in any of the great classes of machine tools. A single operation may be done in one machine, or a number successively.

Much complication is necessarily introduced into machines which do automatically what is otherwise performed by human labour; special devices for controlling the movements have to be included, as cams, or formers, involving considerable expense before ever a single piece is turned out. Often, however, the inclusion of an automatic device means but little more complication than that introduced when hand-operated methods are adopted. Many automatics have developed slowly from semi-automatic types, as the need for them has arisen.

The broad question of automatic *versus* semi-automatic, or hand-operated mechanism, is occupying a large amount of attention at the present time; the tendency is constantly to devise automatic machinery to eliminate labour. The number and variety of mechanisms are always increasing, with benefits in the majority of cases. Manufactures are cheapened and a better class of article produced. Apart from this, the employment of the certain and precise automatic movement is a step in advance of human work, on which too much dependence cannot be placed.

It is impossible to denote here the immense number of mechanisms to which the term automatic is now prefixed. They number hundreds. Many will be found described under other headings. A few only are noted in the pages immediately following.

Automatic Reversal.—In a great number of automatic and semi-automatic machines, provisions for effecting automatic reversals of the parts are necessary, such as in altering the direction of rotation of pulleys and wheels, and performing the to-and-fro movement of slides. The necessity of having an attendant to reverse such motions is dispensed with wherever possible, because the means whereby reversal can be effected are simple, and effective. The commonest methods of reversing are by shifting belts, and clutches. In the belt design, there are three pulleys, a central fast one, and two side loose ones. These latter carry respectively an open and a crossed belt, thus obtaining revolutions in opposite directions. Either belt is thrown on to the fast pulley, this being effected by striking-forks. The latter are actuated by the moving portion of the machine which it is desired to reverse, such as a slide

rest, or grinding rest; when this arrives at the stage where reversing should occur, it strikes a shipping rod, throwing over the belt desired. Adjustable dogs on the rod permit of the point of reversal being altered.

Although belt-shifting is a very suitable device for some machines, it does not answer sufficiently well for very precise movements. Other means are therefore adopted, such as friction clutches, and claw clutches, which answer more rapidly than a belt. To assist the movement of some of these, springs are fitted to jerk the clutches out of mesh instantly, a very important matter in cases where slides have to work up to shoulders on work being machined. Provision for locking a motion when thrown in must be introduced in many cases, in the form of spring catches, which automatically locate and retain the reversing levers in place until the time arrives for another reversal. A balance weight also is often used to lock reversed portions.

The machines on which automatic reversing devices are employed include a great variety, examples of which will be found throughout this work, as lathes, planing, shaping, slotting, milling, grinding, and other machines, and the methods of fitting can be studied from the illustrations given of these various machines.

Automatic Saw Sharpening.—*See* **Saw Sharpening Machines.**

Automatic Screw Machines. — Automatic screw machines are highly specialised forms of lathes, which perform all their operations automatically, without human intervention. The term "full automatic" is often applied to them, though automatic alone is obviously sufficient to distinguish this type from the semi-automatics, or those which require the services of an attendant to set in motion certain of the parts. The function for which these machines were first designed, that of the production of screws of small sizes, gives them their name, and although many other articles are now made on them, screws still constitute the majority of work turned out, and so the title sticks. Special designs of machines are made for specific operations, and other names are given to these, in order to distinguish them from the standard forms of screw machines—as automatic pin and stud, automatic forming, automatic chucking, automatic cutting-off, and other machines. These vary from the ordinary types, in possessing more or less parts than the latter, according to the range of operations involved. A plain stud machine, for example, need not have nearly so much complication as a more complete type for performing a greater number of operations.

Automatic screw machines must not be confused with **Screwing Machines**, which are a very different class—intended simply for screwing with dies, while the screw machines do many other operations, including turning, drilling, facing, cutting-off, knurling, forming, reaming. Everything in fact that an ordinary lathe can do, the automatic screw machine will also do, but with this difference, that the screw machine is set up to repeat the operations a great many times, for repetition work, so that hundreds or thousands of similar pieces may be produced, within definite limits of size, with the result that they will be interchangeable. The value of this was first appreciated in the case of ordinary screws, which must obviously be interchangeable in their holes, and machines were devised for use in the gun and sewing-machine trades, primarily in America. Though much appreciated in such special manufactures as these, it was not supposed at first that automatic screw machines would be of much use to engineers, partly owing to the fact that only very small pieces were at first made on the machines, the latter not being sufficiently large or powerful to tackle the heavier work common to engine-builders, and machine-makers. In time, however, larger machines were built, chiefly at first for producing screwed studs, set screws, bolts, and plain pins of various kinds, which are always used in great quantities in machinery of practically all varieties. From this stage it was but a step to the handling of various other articles, comprising practically all classes of circular work, in the way of pins, handles, cones, collars, cups, shells, nuts, rollers, the diameters of which now run up to as much as 6 inches, which the hollow spindles of the machines take in the form of bar or tube passed through.

The use of a long rod or bar, from which the

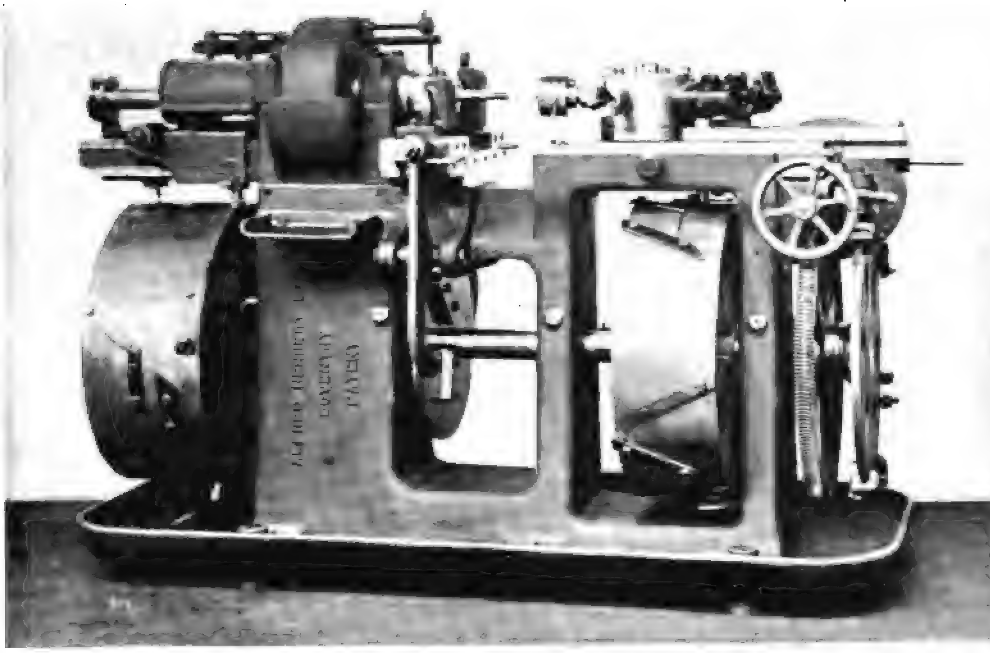


Fig. 164.—Automatic Screw Machine (Standard Type). (A. Herbert, Ltd.)

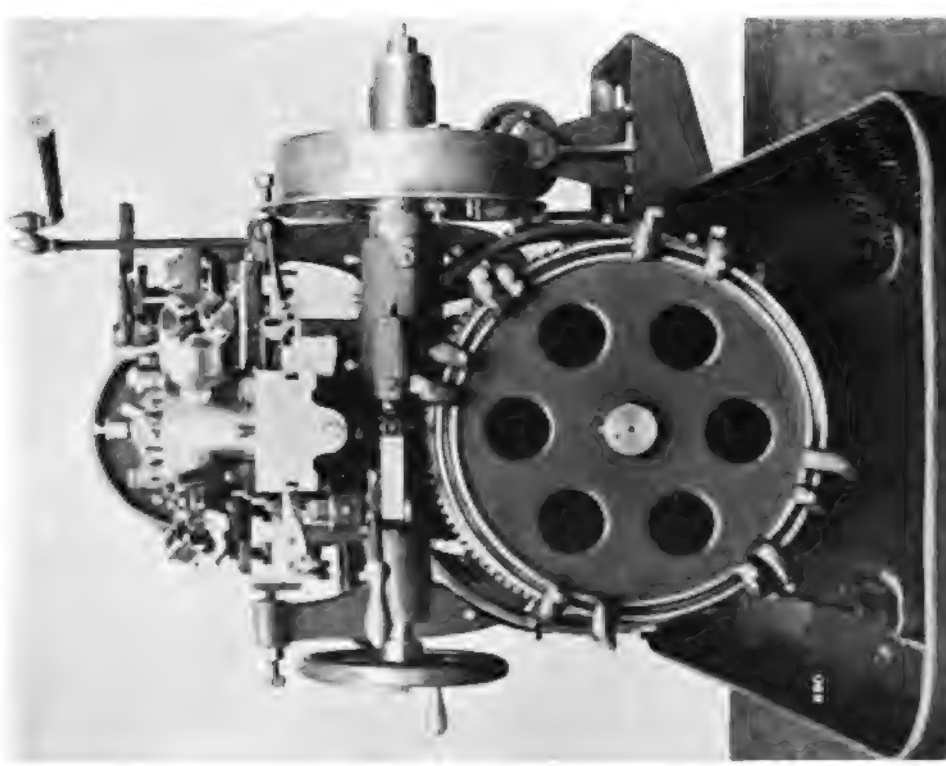


Fig. 165.—End View of Automatic Screw Machine.

To face page 230.

pieces are turned, screwed, &c., and then cut off in succession, is one of the chief reasons for the great success of automatics. In the ordinary lathe, the usual practice for turning pieces having irregular or shouldered shapes is to first forge them to the approximate shape, and then put between centres, and turn them up to the finished outlines. Instead in the automatics (and also in semi-automatics), a long parallel bar is passed through the hollow spindle, and sufficient of it left projecting at the front end to give the length of article required. The latter is then turned, and otherwise tooled until finished, after which it is cut off, and the bar fed through for another sequence of operations. The reduction of the parallel bar necessarily means a certain waste of material in the form of cuttings, but this is counterbalanced by the saving of the cost of forging, and in the separate chucking which has otherwise to be done, if each piece is made as a separate length. The uniformity of sizes, and long life of the tools, is also induced by employing regular sizes of material. Separate forgings would be more irregular, and their scale would quickly ruin the tool edges.

Bars of iron, steel, brass, gun-metal, delta metal, &c., are employed for the production of pieces in this way, and the only duty of the attendant is to insert the length of bar in the spindle, after which the machine goes through all its operations in succession, repeating them until the material is used up.

The arrangements of automatics in the shop are different from those of ordinary lathes, due to the fact of the bars of material projecting out so many feet. If all the machines were placed in line, the bars would foul the next machines. The lay-out shown in Fig. 162 is therefore adopted, the machines being angled slightly, so that the bars, shown as black lines on the diagram, pass behind the adjacent machines, and so enable them to be located closely together. The gangway between the two rows of machines enables the attendant to walk down, and inspect them, and to insert fresh material from the back gangways as required. The countershafts are not angled, but are placed parallel, as indicated by the dotted lines of centres; the belts twist themselves sufficiently to accommodate the want of parallelism between line and machine pulleys.

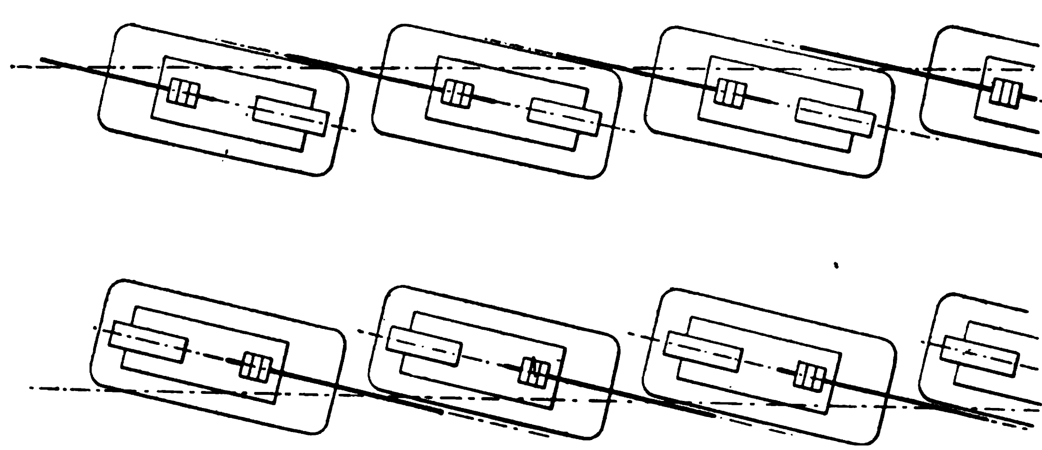


Fig. 162.—Illustrating the Lay-out of Automatic Screw Machines on a Shop Floor.

Although bar work has been, and is still the most valuable feature of automatic screw machine production, much has been done in recent years in the way of automatically handling castings, and forgings of irregular shapes which would not be economically produced from bar. Much of this has been deemed impossible to treat automatically, yet ingenious devices have been evolved for carrying the separate pieces in shutes or racks, feeding them singly to a chuck, which grips them until the tooling operations are finished. Many classes of wheels, gears, and gear blanks, collars, &c., are now treated in this fashion, with great economies

over the previous practice of ordinary lathe production. But of course a sufficient run of similar articles must be assured, in order to make the cost of the rig-up pay for itself.

Although automatic screw machines are strictly lathes, they possess but few resemblances, beyond revolving spindles, and sliding portions. Not only are the work-carrying and tool-carrying portions different, but the necessary devices for effecting the automatic movements introduce extra complications which have no equivalent in plain lathes worked by attendants. Even the tools employed in the automatics differ in many respects from those used by ordinary turners—chiefly due to the necessity for ensuring the production of uniform and definite sizes in the duplicate work turned out. There is no question of measuring the work of automatics after the machine is finally set up, and adjustments made; hundreds of pieces may be made in succession, with only an occasional checking of random units, to see that the limits of accuracy are not altered, due to the wear of tools, or possible slight derangements of the mechanism.

The great value of automatics, therefore, lies in their accurate production of repetition pieces, combined with the minimum of attendance; one man can look after a number of machines, up to as many as a dozen in certain cases, where his only duty is to feed the machines at intervals, remove chips, and finished pieces, &c. Claims are often made that a hand-operated screw machine, in charge of a capable man, will exceed the quantity of work turned out on an automatic; this may be so for short spurts, but in continued regular work the automatic scores. Several reasons may be given for this, the principal of which are that the automatic is untiring in its cycles, keeping up a uniform speed hour by hour, and this uniformity tends to ensure exact work, as well as treating the tools fairly; a hand operator often forces slides too quickly, putting too much work upon the tools, so that their life, and the quality of product, are both affected.

The reason why a good run of work is essential to employ automatics economically lies in the amount of special setting up and tool-making necessary for any particular piece, more especially in the case of awkward and complicated shapes, involving curves and irregular outlines. But the setting up of automatics for plain classes of jobs has been much simplified, and the amount of changing to be done for varying sizes of plain parallel screws, pins, collars, &c., is so little, that numbers as low as one or two hundred can be made with economy, including the time taken in setting up for the job. In such a case, what are termed standard tools are used, only involving some adjustment for size, and the lengths cut are determined by the setting of the machine parts. But if tools have to be specially prepared, several hundreds of pieces must be wanted to pay for the cost involved. In many cases—in fact in the majority of automatic work—thousands of duplicates are made, so that expenses of machines and outfits are outbalanced easily by the results achieved in saving of labour costs, and uniformity and accuracy attained.

The essentials of an automatic screw machine may be stated concisely thus:—A revolving spindle, to carry the work. This spindle, in the case of bar work, is hollow, so that a long rod may be passed through. Devices for feeding and gripping are provided, automatically operated by cams. The motions are so timed that on the completion of a piece on the end of the bar, the grip on the latter is released, it is fed through the spindle to a predetermined distance, and again gripped. For operations where screwing is involved, a reversing motion is often fitted to the spindle, so that it may be run backwards quickly to unscrew the die or tap from the work. Alternatively the die may be of the opening type, in which the chasers open off the screw, and retire from it. Provision for changing the speed of rotation may also be incorporated, so that the rates of revolution of the work can be altered to suit the operations. There is, for instance, a great difference in the economical speeds at which turning, and screwing may be done.

The devices which carry the cutting tools comprise a turret, and a cross slide. The former is of circular shape, having a number of holes, from four to six in number, to take a variety of tools. The turret is controlled by cams, which travel it along during cutting, and

backwards, rapidly, when the operation is concluded; on this return stroke the turret partially revolves, so bringing another tool into line ready for the next cut.

The cross slide, or slides (there are very often two), are fed laterally, with levers actuated by cams, giving inward and backward motions, similarly to the cross-working slide of a lathe. There are many variations on this common design, but the principles remain broadly the same.

actual rate at which the work is tooled is much too slow to waste in travelling the tools up to the position where cutting commences, so that speeding is done to travel the tools up rapidly, until just before the work is reached, when the slower cutting rate is substituted. This fast speed is also employed when withdrawing the tools, so that the least possible time is lost in getting the succeeding tool into operation.

All the motions of an automatic screw machine being controlled from a single source—from the

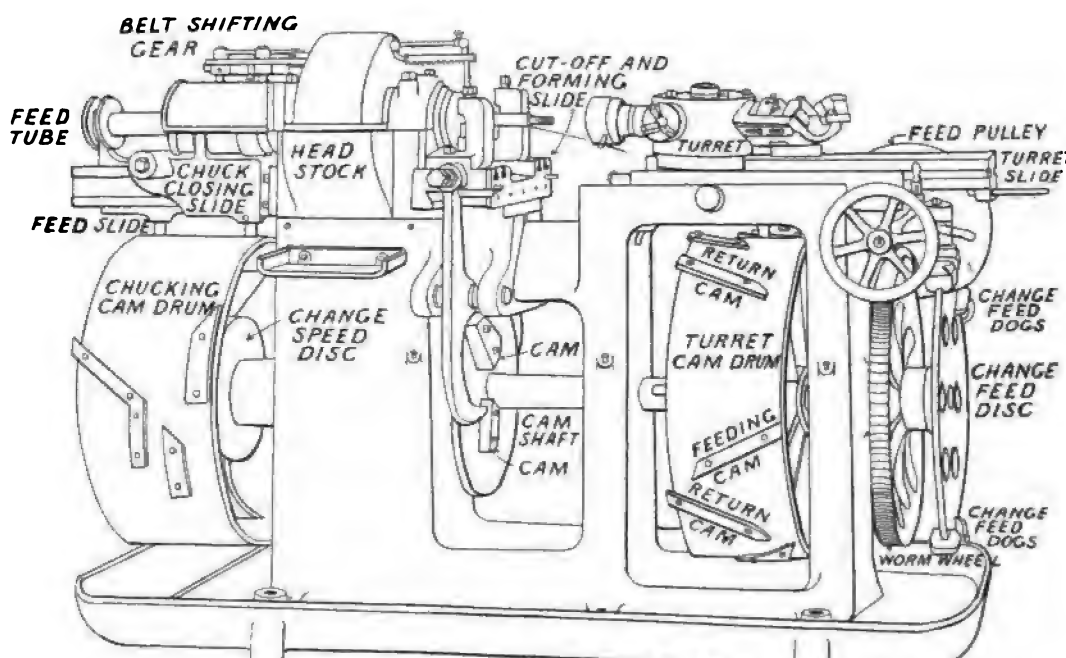


Fig. 163.—Name Chart, Automatic Screw Machine.

The provisions introduced for adjustments of all the principal parts to suit various jobs are perhaps the most interesting features of the automatics. These adjustments are effected by the use of the cams and dogs which govern the rates of speed, of feed, and the periods at which the various movements occur. The latter especially need exact and minute settings to produce work correctly, and to avoid clashing of the turret and the cross-slide tools. Beyond the spindle speed alterations already mentioned, differences in the rates of travel of the turret and cross slide are made, in order to economise time and quicken production. The

shaft which carries the cams—the various movements cannot get out of time with each other, but must go through their operations in sequence, working to the limits provided in the primary setting of the machine. After starting up, nothing is done but to feed the material in. The only things which could happen to the detriment of the product, from the point of view of accuracy, are accidental working loose, or slight shifting of cams, &c., which might affect dimensions, and the wear of the tools, which would also have its effect upon the sizes cut. The first possibility is guarded against by adequate and secure methods of clamping; the

second by properly forming, tempering, and lubricating the tools. It must be remembered that the duty of the cutters is very light in many cases, and frequently a finishing tool follows a roughing one, so that the wear on the former being exceptionally slight, due to its light duties, enables it to cut correct sizes for a long while before needing re-setting. Automatics often run for several days, producing thousands of duplicate parts, without the tools being changed; on brass and other soft materials the endurance is of course longer than on hard steels, which are more severe on the tools, necessitating frequent sharpening.

Taking up a more detailed study, the named diagram, Fig. 163, of a standard type of machine by Alfred Herbert, Ltd., gives a good idea of the different parts, and their functions. This illustration shows the setting up for ordinary work, with standard cams, which lend themselves, by adjustments, to the production of various lengths and diameters of work, plain and shouldered, such as pins, and screws, which constitute the largest proportion of work done on automatics.

The drum on the extreme left serves to operate the chucking mechanism in the spindle, by the set of cam strips bolted to the surface of the drum; as the latter revolves, the strips in turn push the two pins seen immediately above the drum (*see also* the photograph, Fig. 164, Plate XIV.), and perform the releasing of the bar, its feeding forward, and re-gripping. The cams for loosening and tightening do not need adjustment after setting for a definite diameter of bar, but the cam for feeding to length (not visible) is easily altered to suit the distance it is required to push the rod through the chuck, when batches of articles of varying lengths have to be produced.

Taking next the other large drum, underneath the turret, the cam strips on this serve to travel the turret slide up rapidly until the cutting starts, then more slowly to the end of the cut; a rapid backward movement then occurs, during which the turret is revolved by mechanism contained in the slide, bringing the next tool into line with the spindle, ready for a succeeding cut.

The cams for operating the cross slide are attached to a disc only, since no longitudinal travel has to be imparted, which would necessitate the use of a long drum. The cams press against long pivoted levers, one of which is seen at the front. The other ends of these levers push the cross slide over, or pull it back. There are two tool-holders on this slide, one of which may carry a forming and the other a cutting-off tool, which are brought into action at appropriate intervals.

The large worm wheel seen to the right is for rotating the cam shaft. This wheel is driven by a worm through the medium of belt pulleys, which are seen in the photo of the end of a machine, Fig. 165, Plate XIV. Two different rates of speed are given to the cam shaft, which are obtained by the use of adjustable dogs on the disc at the extreme right (*see also* the end view, Fig. 165, Plate XIV.). It would obviously waste much time if the cam shaft revolved at a constant speed, which would have to suit the slowest operation involved in turning or screwing. The quick speed is therefore thrown in at certain intervals, as during the running back of the turret or cross slide and the feeding forward of bar. The method of throwing in the fast or slow speeds at the proper times is simple; a number of blocks or dogs are pinched with screws to the periphery of the disc at the end, and these strike a shipping lever, throwing in the fast or slow speed to the worm, driving the large worm wheel. The locations of the dogs around the disc determine the intervals at which the speeds are changed, and as the dogs can be shifted to any positions, the alterations can be timed exactly as desired.

These dogs are also utilised when it is desired to miss one or more operations in the turret. If, for instance, only two of the holes in the turret are carrying tools, the other three, or four, as the case may be, will only make idle movements, but it is still necessary that the turret slide shall go through the to-and-fro motions, in order to get the turret revolved. The movements for the empty holes are therefore performed at the high speed, to save time. This is done by setting shifting dogs to keep the rapid speed on until the idle cycle has been gone through, when another dog throws in the

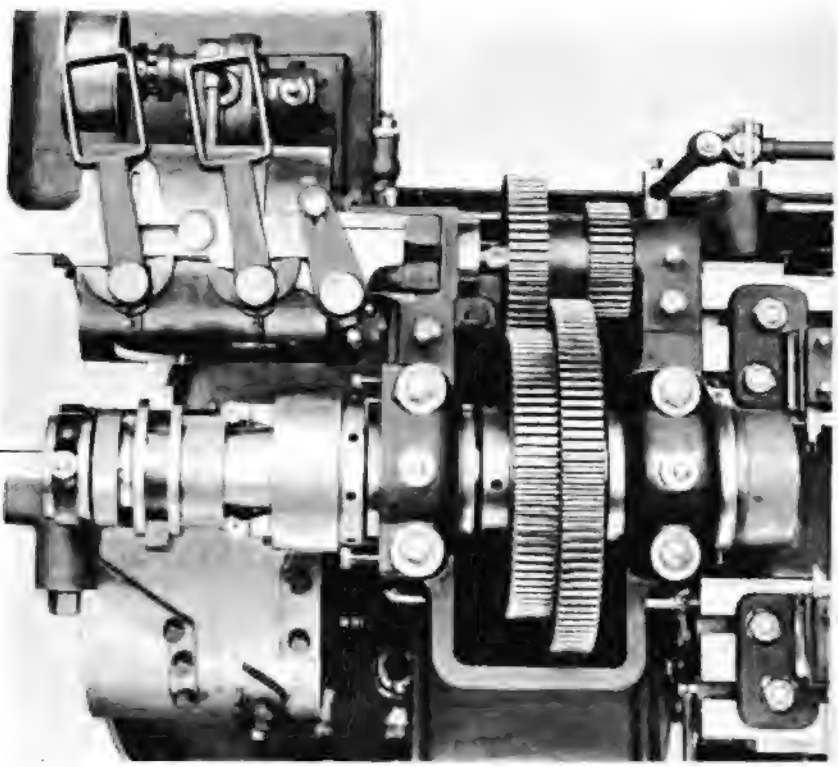


Fig. 166.—Plan of Double-geared Head. Automatic Screw Machine. (A. Herbert, Ltd.)

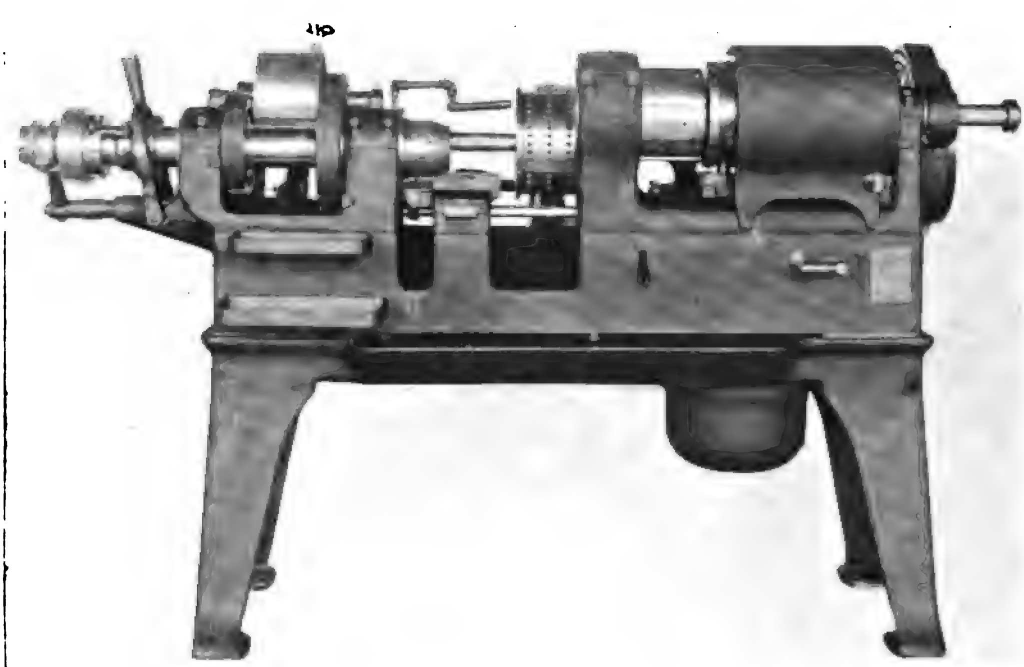


Fig. 170.—Cleveland Automatic Screw Machine.

To face page 234.

slow cutting speed. Such variations are also employed to hurry the cross slide up to, and back from the cutting positions. The hand wheel seen in front of the worm wheel is for effecting complete or partial rotations of the cam shaft, when setting up the machine, and adjusting cams, &c.

XV., which is a plan of a head, with guards removed) are—greater power, due to the gearing up, and the fact that comparatively narrow belts can be used when the pulleys are placed behind, and gears used; the headstock is much shorter, as instead of wide pulleys, the narrow gears only have to be accommodated between the

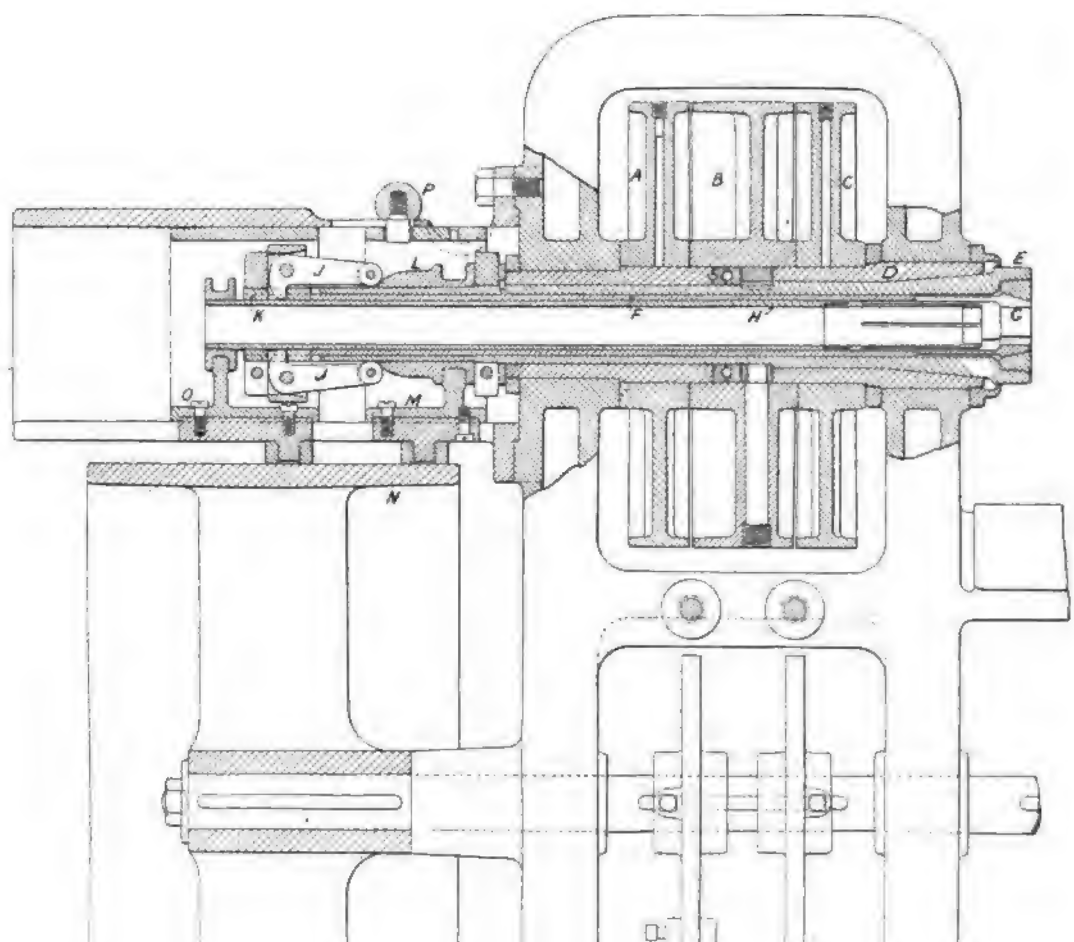


Fig. 167.—Section through Head and Work-spindle of Wolseley Automatic Screw Machine.

bearings. In the headstock shown in the photo, the two belt shifting forks seen in the left-hand top corner throw on fast or slow belt speeds when required, being actuated by cams from the cam shaft, one pulley being driven from the overhead at a higher rate than the other. By crossing one belt, a reverse motion for tapping can be obtained. The use of the

Considering next the spindle-driving arrangements; in the Herbert machines the belt pulleys are not placed directly upon the spindle, as is usual in ordinary lathes, and in some other types of screw machines. The advantages claimed for the practice of putting the belt pulleys separately behind the head, and driving to the latter with spur gears (*see* Fig. 166, Plate

two sets of pinions and wheels enables two differing ratios to be had, as desired, according to the size of the work tooled. In conjunction with the countershaft, twelve speeds in all can be got to the spindle.

The principles of spindle gripping and feeding mechanisms are practically the same in all

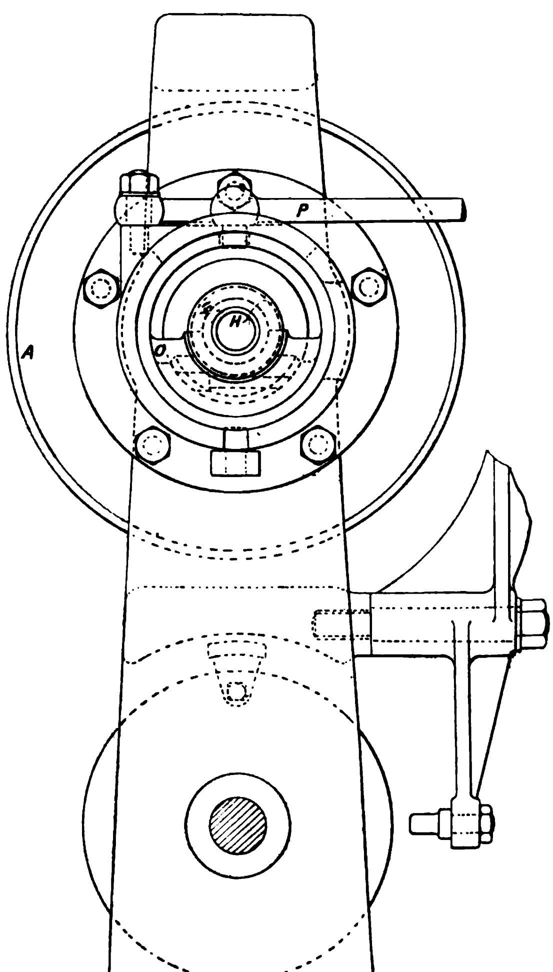


Fig. 168.—Rear-end Elevation of Wolseley Head.

machines. The sectional drawing, Fig. 167, of the spindle of a machine by the Wolseley Tool & Motor Car Co., Ltd., represents the typical pattern, which differs only in proportions and details in other types. Here it will be seen that three pulleys, A, B, and C, are mounted, not directly upon the spindle, but upon a bush or sleeve D, held in the headstock holes. This relieves the spindle E of all side strain due to the pull of the belts, and prevents uneven wear. The pulleys A and C run loose upon the sleeve D, at different rates, fast and slow, and either can be thrown on separately to the wide middle driving pulley B, attached to a ring keyed on the spindle. A ball thrust is fitted next this collar, to relieve the end pressure. Fitting within the spindle bore is a long tube F, having at its end a split chuck G, tapered to jam into a plug screwed in the spindle end. Within F is another tube H with a spring split end screwed to it. Compare with the end view, Fig. 168.

It will be evident that the act of pushing F outwards would grip the chuck end around a bar fitting snugly within it, and this function is performed by the two levers J, J, the hooked ends of which press against the face of a collar, touching the end of F. These levers are actuated by the sliding ring L, the body of which coerces the roller ends of J, J, causing them to open out. L is moved along by a slide M, which is driven by a cam strip attached to the cam drum N, set to just close the chuck sufficiently tight. The tube H is also slid endwise, by a slide O, also actuated by a roller pushed by a cam strip on N. These pins have been referred to previously in a similar class of fitting, mentioned in connection with Figs. 163 and 164.

The sequence of operations is as follows:—When a bar is to be loosened, the slide M goes to the right (in the position seen in the figure), thus allowing the spring chuck to release itself from the bar. The slide O then travels to the right, pushing the tube H, on the end of which is the split portion. The latter is made to just grip the bar, so that it is carried along with the tube. This constitutes the feed of the bar. When the length of travel desired is reached, M moves to the left, pressing levers J, J, on the end of F, and tightening the chuck around the bar. Slide O then moves to the left again, drawing back the tube H, with its feeding finger, ready for another pushing of the bar when desired, after the tooling operations are finished. For working the chuck by hand, when making adjustments in setting, the hand lever P is provided, actuating the slide M.

Alternatively the chuck end, at G, may draw inwards, as is the case in many spindles operated on the spring chuck principle.

The general construction of the Wolseley machine may be studied from the complete drawing, Fig. 169. The headstock, of which a section has just been given, is seen on the left, with the operating drum beneath. The belt shifting levers are also noticed in front of the pulleys. Small discs, having adjustable dogs pinched on them, provide the means whereby these levers are thrown over. Another disc, further along, under the cross slide, moves the latter, with cams. The turret, which is in this case of horizontal cylindrical form, has the holes for tools located in the end face. It is thrust forward by a cam and pin embodied in the construction, varying rates of feed being produced by means of a friction disc arrangement, which is varied by the large disc seen beneath the turret, carrying a circle of flat-headed screws, which are adjusted to stand out at various distances, and so make a cam-like path to control the pivoted lever and roller seen alongside. The change gears at the end serve to vary the speed of the cam shaft.

The Cleveland automatics, Fig. 170, Plate XV., have a cylindrical horizontal turret, standing opposite the work spindle, as in the Wolseley. Varying rates of feed can be imparted, to suit each tool held in the turret, by means of a large wheel carrying segments which control the movements. We cannot attempt to describe the large amount of detail involved in the mechanism, but the effects are similar to other automatics — to-and-fro movements of the turret, partial rotation to bring fresh tools into line with the spindle; a cross slide, carrying either one or two tools, and a spindle provided with rapid reverse motion,

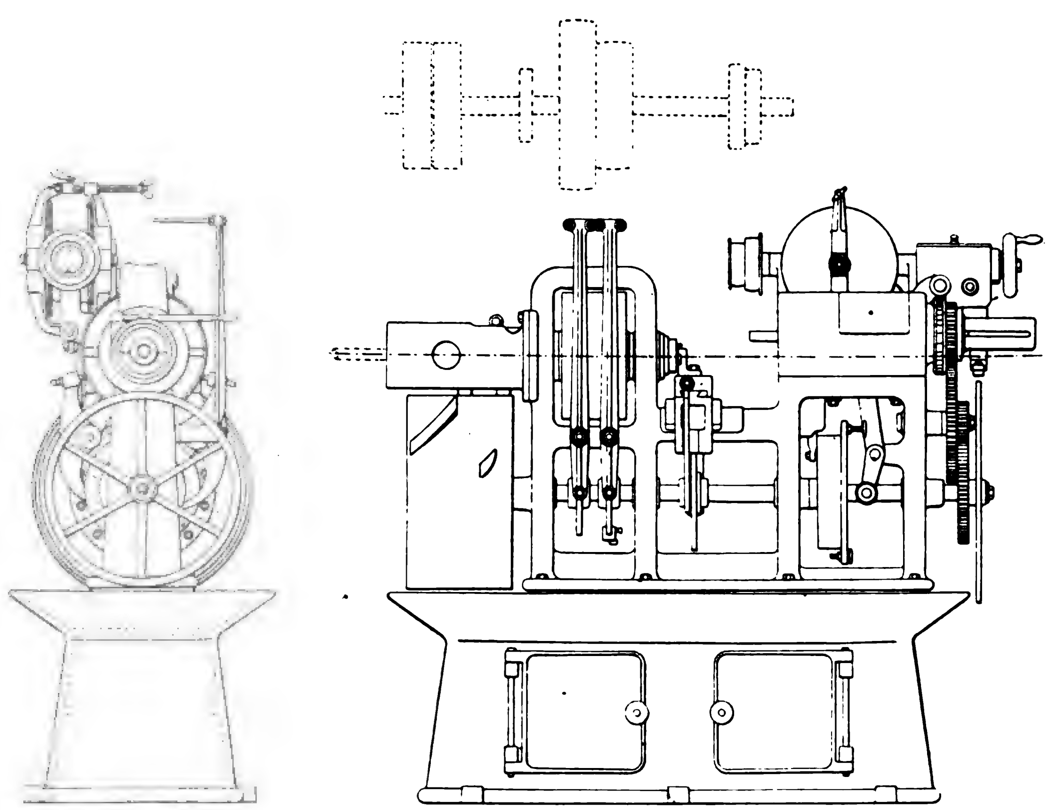


Fig. 169.—End and Front Elevations of Wolseley Machine.

or simply higher speed in the same direction, as desired.

The Brown & Sharpe automatics, front and rear views of one size of which are given in Figs. 171, 172, differ essentially from other types in several respects. The turret stands vertically, its periphery facing the spindle, and the various motions are operated by disc cams

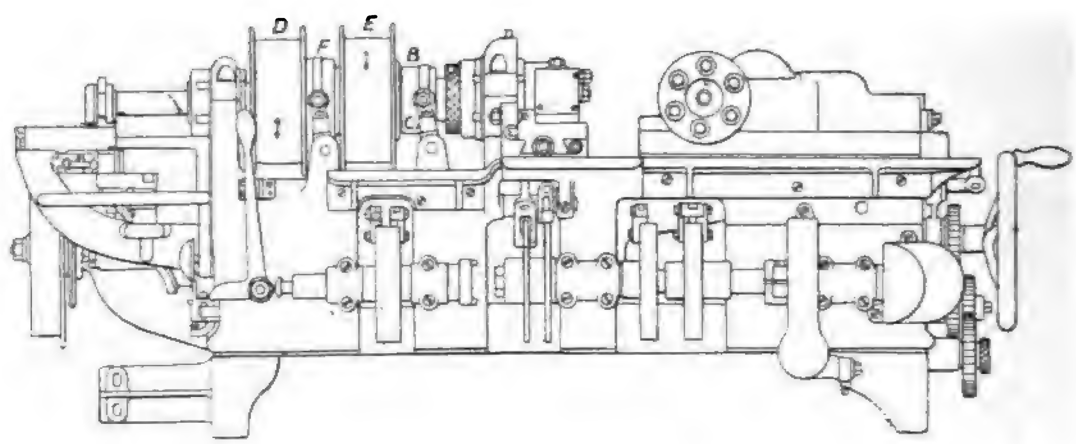


Fig. 171.—Front View of Brown & Sharpe Automatic.

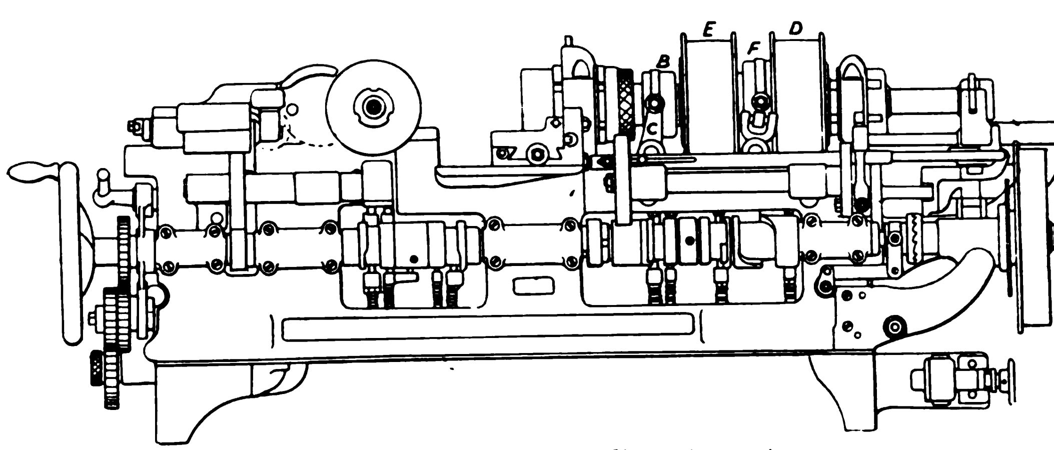


Fig. 172.—Rear View of Brown & Sharpe Automatic.

on a horizontal shaft lying in front of the machine. The peripheries of these cams are cut to suitable shapes, imparting the requisite motions to the levers which perform the turret slide travel, revolution of the turret, feeding and gripping of material, and reversal of spindle. The section through the headstock and spindle, &c., Fig. 173, shows the feed tube A,—the innermost one, having the split end for gripping the bar. This tube is pushed along with the collar at its extreme left, in the same manner as already described in connection with the Wolseley design. The chuck tightening is effected by the sliding collar B, pushed along through the medium of a cam, and the lever C seen in the front and back views, Figs. 171, 172. The inside of this collar B coerces two hooked levers pushing on the end of the sleeve which closes around the chuck at the nose. The two pulleys D and E running in reverse directions, are engaged with the spindle by the friction clutches seen within them. A sleeve F, moved similarly to B, throws—through the medium of the curved dogs seen inside it—either clutch alternatively into engagement with its pulley.

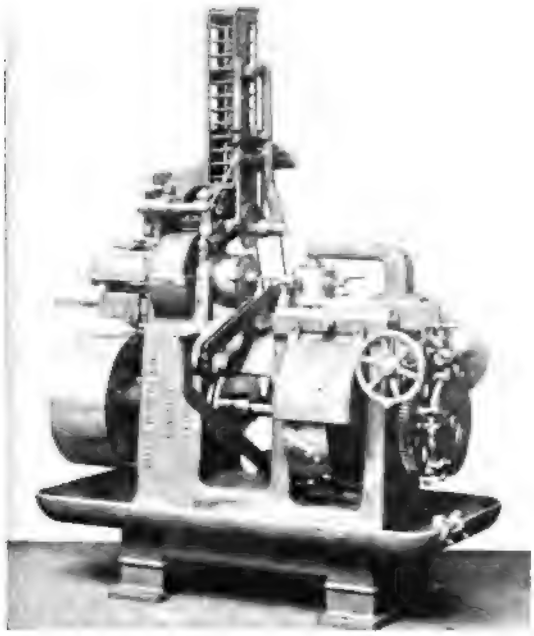


Fig. 174.—AUTOMATIC SCREW MACHINE, WITH MAGAZINE ATTACHMENT.

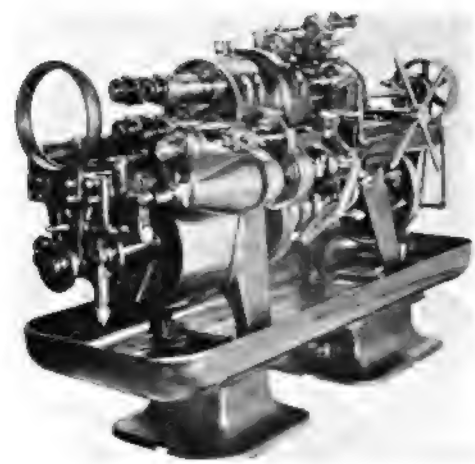


Fig. 175.—FOUR-SPINDLE AUTOMATIC SCREW MACHINE. (Acme Lathe & Products Co., Ltd.)

Fig. 177.—ERECTING DEPARTMENT FOR AUTOMATIC SCREW MACHINES. (Brown & Sharpe Manufacturing Co.)

To face page 238.

There are many interesting details in these machines, too elaborate to be treated here. Although the automatic has a different appearance to the others previously illustrated, the functions and the operations performed are similar.

A point which may be noted in connection with all automatic screw machines is that although a turret may have a capacity for say five, or six tools, and all of these will be occupied on some classes of jobs, there are certain instances in which but one, or two turret operations are required, as screwing, turning down, or pointing, or drilling. In such a case what is called a double cycle is gone through, that is, during one revolution of the main cam-drum two pieces of work are produced, instead of one only, where considerable complication is introduced. To meet the demand for a large range of this kind of work, special types are sometimes employed, having no turret, but a simple slide only, which carries a screwing die, or turning tool only.

The feeding of single pieces to automatic screw machines, as already mentioned, has developed very rapidly, with a consequent invasion of the work which it was deemed only possible to perform by hand methods. One of the earliest examples of this was that of feeding in studs through the back of a machine spindle, to be screwed, after this operation had been done upon one end. The studs lay in an inclined shute, and were admitted one by one as required, being gripped by the chuck, screwed, and then automatically ejected as another stud came into place. The device of passing articles through the hollow spindle being only applicable to small diameters, a very large class of mechanisms have been devised for chucking from the front, above the spindle nose, just as an operator would do. A typical example of this is seen in the photo, Fig. 174, Plate XVI., showing a machine with a magazine attachment for cast-iron skew bevel gears. A pile of these are held within the vertical frame seen above the headstock,—laying in a horizontal position upon each other,—and the lowermost one is first released, drawn downwards, hung on to a pin, which then gives a quarter turn, so bringing the casting into an upright position. Another pin then takes the wheel, lowering it down opposite the chuck jaws; the turret slide then comes along, and a plunger on it pushes the wheel into the chuck, the jaws of which close and grip the outer diameter. After the boring and facing operations, a pin on the turret engages in the hole in the wheel, and as the chuck jaws are released, draws it away. The wheel then falls into the shute seen in the front of the machine, runs down it into another, and so to the back of the machine where a box catches it. All these operations are entirely automatic. The aid of the turret is often requisitioned in the manner named, to push and withdraw pieces from a

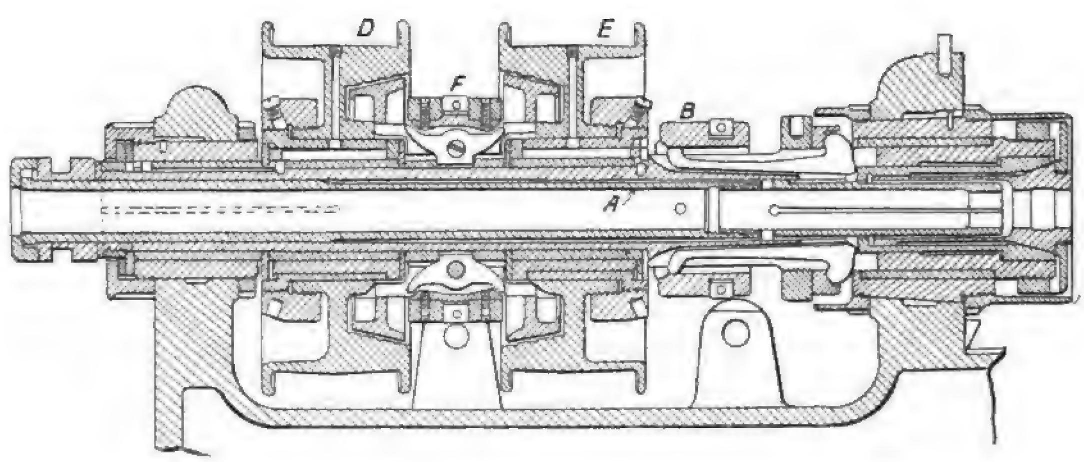


Fig. 173.—Section through Headstock and Spindle, Brown & Sharpe Automatic.

chuck, where a mechanism above the spindle nose could not effect this without considerable complication. *See* **Magazine Feeds** for details.

A radical departure from all ordinary automatic screw machines is that of the four-spindle design, shown in Fig. 175, Plate XVI., the view being taken at the headstock end. Its main feature is that of four distinct work-carrying spindles, in place of the usual single one. Each spindle carries a bar of material, and opposite each is a tool carried in a vertical turret-shaped slide. Each bar is operated on simultaneously by the tool opposite it, and after the completion of the cycle,—that is, the time occupied by the tool longest in operation,—the entire set of four spindles are given a quarter rotation, presenting each bar to a fresh tool. The speed of production of a given piece is thus greatly quickened, as four such pieces are in partial stages of completion at the same moment, instead of only one, as in ordinary machines. At each complete revolution of the work spindles (which go by quarter turns) a piece is finished, and cut off by the cross slides. There are two of these, and as more than one tool may be held in the tool slide, a number of operations,—as many as eight,—can be performed on a piece. Fig. 176 is a section through the headstock, through two of the spindles; these revolve within the cylinder seen, which in turn makes its quarter turns within the outer fixed casing. Each spindle is driven from the central shaft, which carries a pinion, engaging with ones on the spindle bodies, as shown. They are therefore unaffected by their rotation bodily around the central axis, but continue to run during the rotation. The turning of the cylinder is performed by the worm wheel seen, which is constantly revolving; at the appropriate intervals a pin is pushed into a slot in the worm wheel, so causing the latter to drive the cylinder around. During this period the locking bolt is withdrawn from the cylinder, and is reinserted after the quarter turn has taken place.

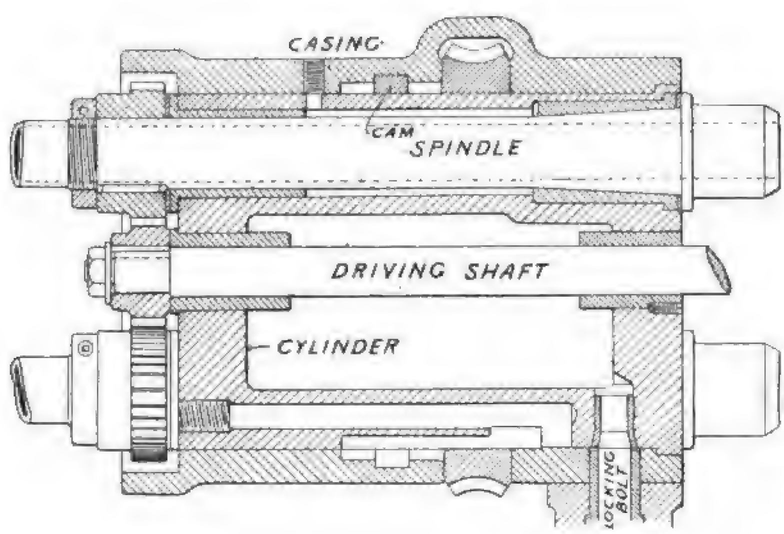


Fig. 176.—Section through Head of Four-spindle Machine.

A change speed mechanism on the Hendey-Norton principle is fitted to the machine, to suit varying work.

Another special type of machine is the Spencer, the feature of which is a double-turret arrangement, comprising two vertically placed discs, carrying tools. There are two work spindles, which revolve and present the bar to the turret tools, the latter revolving successively as required.

The photograph, Fig. 177, Plate XVI., gives an insight into the methods of manufacturing automatic screw machines, of which some dozens of similar type are seen in the course of erection. These, in common with other machine tools, are standardised and made interchangeable, and their very extensive employment is evidenced by the fact that such methods can be adopted in the construction of what, not so long since, were very rare and special machines, seen in but few shops, and hardly ever in engineers' works.

Other remarks concerning automatic screw machines and their outfits will be found under **Box Tools, Camming, Dies, Forming Tools, Knurling Tools, Magazine Feeds, Taps, Turrets, Wire Feeds.**

We have concluded that it would be more advantageous to bind two volumes of this Encyclopædia in one volume. That is, volumes One and Two, Three and Four, Five and Six, Seven and Eight, and Nine and Ten, are each bound together; thus publishing the work in five bound volumes, instead of ten.

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OF

PRACTICAL ENGINEERING

AND ALLIED TRADES

A PRACTICAL AND INDISPENSABLE WORK OF REFERENCE FOR THE MECHANICAL ENGINEER, DESIGNER, DRAFTSMAN, SHOP SUPERINTENDENT, FOREMAN AND MACHINIST.

Encyclopædic in scope, thorough and practical in its treatment of technical subjects, simple and clear in its descriptive matter, and without unnecessary technicalities or formulæ. The Articles are as brief as may be and yet give a reasonably clear and explicit statement of the subject, and are written by men who have had ample practical experience in the matters of which they write.

EDITED BY

JOSEPH G. HORNER, A.M.I.MECH.E.

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ASSISTED BY A CORPS OF PRACTICAL MEN, EACH A SPECIALIST IN THE SUBJECT OF WHICH HE WRITES.

PROFUSELY ILLUSTRATED.

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The Encyclopædia

OF

Practical Engineering and Allied Trades.

Automatic Stokers.—*See* **Mechanical Stokers.**

Automatic Testing Machines. — *See* **Testing Machines.**

Automobile. — A mechanically propelled vehicle. The earliest recorded instance of an actual road trial of an automobile is that of Cugnot in 1769. The speed attained by this was about 2¼ miles per hour. In form the machine was a tricycle, propelled by steam, the boiler being carried in front, and overhanging the single driving wheel. The engine consisted of two single-acting cylinders the pistons of which were connected to arms with pawls driving two ratchet wheels attached to the driving wheel. Owing to the overloading of the single driving wheel the machine was too unstable, and overturned on rounding corners. It is still in existence in Paris. Long previous to the Cugnot tricycle the automobile had been foreshadowed by Sir Isaac Newton about the year 1680, who proposed a wagon provided with a boiler, a jet of steam blowing against the air being expected to propel the wagon by its reaction. Dr Robinson suggested a steam road carriage to James Watt in 1759, but without result. Further suggestions were made by Dr Darwin, and Boulton. Others experimented from time to time, and in some cases working models were constructed, such as that by Murdoch. The first road carriage to be built and run in England was constructed by Trevithick about 1802, but after a number of runs, in and about London, the machine was dismantled, and the engine sold for other uses. A steam carriage patented by Gordon in 1824 was propelled by an arrangement of cranks and levers connected to feet which were intended to push the vehicle along, but after trials extending over several years the whole thing was given up as useless. A steam carriage was also built by Griffith about 1822, and this was probably the first instance of an air-cooled condenser, the exhaust being led into thin brass tubes exposed to the air. Unfortunately this machine was never tried on the road. The Burstall & Hill steam carriage had all four wheels as drivers, but in spite of this the speed was but 4 miles per hour.

The first really practical steam carriage to be built in England was that constructed by W. H. James in 1829, under the patronage of Sir J. Anderson. This was similar in form to the stage coaches of that day, and at times attained a speed of 15 miles per hour. About this time patents for steam carriages became more frequent, and trials on the road were made. Summers & Ogle built several steam vehicles, the boilers having "Field" tubes, and the speed reached as high a value as 24 miles per hour. Sir Goldsworthy Gurney built several steam coaches, commencing about 1822, and was, no doubt, considerably assisted by the experience of other experimenters. His boilers were of the water-tube type, and curiously like the present-day water-tube boiler. The defective nature of the tubes made in his time militated against the perfect success of the boiler, but high pressures were recorded. Owing to the obstructive policy of the road authorities, Gurney eventually abandoned the matter. Hancock was experimenting and building steam omnibuses from about 1830 to 1840, and met with a fair measure of success.

He employed a vertical multitubular boiler, and forced draught obtained from a fan. The fuel feed was from a magazine, a method employed in recent years. Vertical engines and chain driving to the live back axle, which was provided with balance gear, indicated a decided advance in design. Hancock ran lines of omnibuses from London to Islington, Paddington, Stratford, and in and about the city. The usual speed was from 10 to 12 miles per hour, though on good roads 20 miles per hour was often reached.

The steam coaches built in England by Maceroni & Squire about 1834 seem to have been reliable vehicles; one which ran daily between Paddington and Edgeware, completed over 1,700 miles without needing repairs. These carriages had vertical tubular boilers carrying steam at a working pressure of 150 lb. per square inch. The horizontal engine had two cylinders, each 7½ inches bore by 15¾ inches stroke, and considering the steam pressure it is small wonder that this coach averaged 16 miles per hour. Maceroni's steam coaches were also run in Belgium and France. J. Scott Russell constructed several steam carriages from 1834 to 1840, one of which remained in active service till about 1857.

Violent opposition, at times resulting in the destruction of the steam vehicles, from turnpike companies and various local authorities, combined with restrictive legislation, eventually killed the growing industry in mechanical road vehicles, progress being only possible on traction engine lines. Notwithstanding the laws regarding the use of power-propelled carriages, a steam brougham was built and run by Mackenzie in 1874. This had a vertical boiler 4 feet high by 2 feet diameter, with Field tubes, and a double cylinder engine 3¾ inches bore by 4½ inches stroke. A two-speed change gear was used in conjunction with a chain drive to the road wheels. The steam pressure employed was 135 lb. per square inch. The first internal combustion engine for propelling a carriage was patented in France by Lenoir in 1860, but practical application of this form of power was not made till Benz exhibited a carriage at Munich in 1891. This vehicle had a horizontal single cylinder internal combustion engine, the fuel being "petrol" (petroleum spirit). The engine was peculiar in having the crankshaft vertical; the fly-wheel, revolving in a horizontal plane, was of large diameter. The power was transmitted from the engine to a countershaft by two leather belts with fast and loose pulleys, thus giving two speeds, and from the countershaft the power was taken to each of the two back road wheels by chains. A differential, or balance, gear on the countershaft provided for the car turning corners safely. Benz was closely followed by Gottlieb Daimler of Canstatt, Wurtemburg, with a motor bicycle, which was also patented in England. The original Daimler motor was of the two cycle type, the combustible charge being first admitted to the closed crank chamber, where it was slightly compressed by the down stroke of the piston, and was admitted to the combustion chamber above the piston by a valve in the piston head. This type of engine was soon abandoned in favour of the four stroke, or Beau de Rochas, cycle. In France numerous engineers took an interest in the automobile, among whom may be mentioned De Dion and Bouton, Panhard and Levassor, Peugeot, Serpollet, Kreiger, Leon Bollee, all of whom produced practical vehicles. Popular interest soon became awakened, and to foster this, automobile races were organised. The first race of any importance was in 1896 from Paris to Marseilles and back, and the winning car, a Panhard, of 8 HP., made the double journey of 1,690 kilometres (1,050 miles) in about sixty-five hours.

The interest aroused in France and Germany quickly spread to England, and several foreign cars were imported. As the law restricting the speed of mechanically propelled vehicles to 4 miles per hour was still in force, these pioneers were frequently prosecuted for using their imported carriages. Eventually this law was repealed, and the Motor Car Act passed in 1896 allowing mechanical vehicles under 2 tons in weight to travel up to 12 miles per hour. This law came into force on 14th November 1896, and was inaugurated by a tour from London to Brighton open to all cars then in the country. Of the fifty or more cars assembled for the start, only some six or eight arrived at Brighton. Judging from the crowds of people

assembled at the start, and at every town on the route, it was easy to predict that the motor industry would have plenty of interested supporters.

As with many new industries, the automobile movement became a new field for the company promoter to exploit, and the harm done in this instance had lasting effects. At the outset an attempt was made to "corner" all the patent rights, and by charging excessive royalties, to make money quickly and in large amounts at the expense of the various motor firms and their clients. Fortunately this scheme fell through, by reason of some patents lapsing, others being tested and found invalid in the law courts, and new systems being invented the patent rights of which were not controlled by the original syndicate. The automobile industry is now firmly established in a healthy condition, and may be expected to become one of the largest industries of the world. The rapid growth from the crude and inefficient machines of 1896 to the smooth running and reliable cars of the present day, is a proof of the vitality, and engineering skill employed.

Modern automobiles may be divided into those propelled by steam, petroleum spirit, and electricity. Petroleum oil, such as kerosene, and paraffin, has not been used to any extent, up to the present date of writing, as a fuel for automobiles. Some few cars have been constructed driven by oil engines, but their faults have been too evident to warrant their commercial manufacture. Chief among the disadvantages may be mentioned the want of perfect combustion, resulting in smoke, and a disagreeable odour from the exhaust gases. Until a more perfect means of converting the oil into a stable gas is devised, the success of oil motors for vehicle propulsion is doubtful. Carburettors for use with oil engines require to be heated to a considerable extent in order that the oil may be vaporised, but if the heat is too great there is a danger of the oil "cracking," and tarry deposits occur in the pipes and passages of the apparatus. On an automobile the demand for gas varies continuously and between wide limits, and this, in itself, militates against the economical vaporisation of the oil. Carburettors for petrol are far more simple in action, requiring no heating while at use, at least, no greater heat than that of the atmosphere is needed, and the vaporisation is more under control. Improper mixtures of air and gas do not cause so much inconvenience as with oil, hence the petrol motor may be operated with much less skill.

Owing to the fact that an internal combustion motor is not self-starting, it is usual to employ some form of friction clutch, or kindred device, in order that the vehicle may be brought to rest without stopping the motor. Also the internal combustion engine develops power in direct proportion to its speed, other things being equal, so that some form of change speed gearing is necessary to vary the ratio of speed between the driving wheels of the car and the motor speed. Usually this consists of as many pairs of spur gear wheels as the gear ratios required, any pair of which may be brought into use at will and independently. From the change speed device the power is transmitted to the driving wheels by one or more chains and sprocket wheels, or by a jointed shaft and bevel gear wheels.

With a steam-propelled vehicle no clutch is necessary, but the engine is stopped as well as the car. Also the speed changing gear is omitted, except in special cases, such as heavy commercial vehicles, in which it is sometimes imperative to assist the engine by increasing the number of revolutions for a given distance of car movement, when a change gear is employed. With this exception the usual practice is to drive the road wheels directly from the engine crankshaft by means of a chain and sprocket wheels. Steam car boilers are generally of the fire-tube type, and are fired by petrol, oil, and for large sizes with coke. About 1903-4 small light steam carriages of American manufacture were very much in evidence in Great Britain and America. Latterly these seem to have entirely disappeared, probably owing to the constant need for attention to the water gauge, and to the limited radius of travel possible without refilling the water tank. The fire-tube boilers used, although wonderfully good steam raisers, did not permit the condensed steam being returned to the water tank for use over again, by reason of the oil gathered from the engine cylinders. Sepa-

rators have been tried, but were not sufficiently reliable to entirely obviate the risk of a scorched boiler. It is a significant fact that in spite of some thousands of these steam cars being in use, and mostly in technically unskilled hands, there is no instance on record of one of the boilers having exploded.

At the present time the only steam cars on the roads, with the exception of large commercial goods wagons, are those provided with so-called "flash" or "semi-flash" boilers. In its elementary form a flash boiler is simply a coil, or series of coils, of stout steel tube which is maintained at a high temperature by means of a fire, and through which water is forced by a pump. All the water admitted to the tubular coils is converted into steam with great rapidity, but not so quickly as to warrant the name of "flash" boiler. A semi-flash boiler is similar in construction, but the various coils of tube are coupled up in such a manner that the boiler, as a whole, always contains a certain amount of water, a condition not expected with a simple flash-type generator. Both these types of boilers are capable of working at extremely high pressures, and 900 or even 1,000 lb. per square inch is not exceptional. Another advantage of the flash, and semi-flash boiler, is that the steam generated is highly superheated, which results in economy in the fuel and water consumption, for a given power, as compared with saturated steam. The first flash boilers used on automobiles were those of Mons. Serpollet, a tricycle being the first vehicle so equipped, and which easily attained a speed of 15 miles per hour. The Serpollet cars have been constantly improved, and may to-day be said to be among the most perfect in use. The Serpollet boiler is a purely flash generator, and the economy in both fuel and water consumption is very high. An American car made by the White Machine Co. is the leading exponent of the semi-flash boiler, and is a very efficient machine. There are many indications that either the flash or semi-flash boiler is destined to supersede the other types of steam generators, not only for small cars, but also for heavy goods wagons and other purposes. Their advantages may be briefly summed up as, maximum safety from explosion, freedom from incrustation, rapid steam production, economy of fuel and water consumption, and simplicity of handling.

Electric vehicles are at present limited to use in towns, or to a radius of action within short distances of charging stations. Also they are mainly confined to use on roads of good surface, as vibration is fatal to the storage batteries necessary for their operation. In fact, the electric vehicle stands to-day much where it did in the early days of the automobile, *i.e.*, 1896. Improvement seems to be in details, such as the controlling mechanism, and the arrangement and suspension of the motor. Until the really light accumulator, with a high storage capacity, is commercially possible, electrically propelled carriages will only be suitable for urban use and light loads. For details of this subject reference may be made to **Carburettors, Change-speed Gears, Flash Boilers, Petrol Engines.**

Auxiliary Engines.—Small engines provided for supplying boilers with feed water when the main engines and pumps are not in use. Other auxiliary engines are used for driving steam winches, dynamos, steering gears, turning and reversing, ash hoists, workshops, and for barring. The percentage IHP. of auxiliary to main engines ranges from about 3 to 5½ per cent. on battleships.

Auxiliary Feed.—Denotes the amount of water which has to be supplied in ocean-going steamers to make up for leakages at the glands, pumps, &c.

Auxiliary Hoist.—A second set of hoisting tackle fitted to an overhead travelling crane, generally of the electrical type, the reasons for which are these :—

Many loads, often the larger majority, which have to be lifted in a shop, are much below the maximum power of the crane. Thus a 20-ton crane may be more often engaged in hoisting loads of from 1 to 10 tons, than those of between 10 and 20 tons. To lift light loads with heavy tackle means employing a high-powered motor, and heavy drums and gears, absorbing much power, due to mass and friction, besides which speeding up has to be done, without, however, attaining so high a speed as is desirable for the rapid lifting of light loads. Hence the advantage of fitting a

separate little set of hoisting mechanism adjacent to the larger set, to take the place of the latter when light loads have to be lifted. It is a set complete in itself, having its own motor, rated suitably to the load it has to carry, its own gears, drum, and chain or rope. The power of the auxiliary hoist is settled by the character of the work done in the shop, for which the traveller is designed. But generally its capacity is one-fourth or one-fifth that of the main hoist. A 20-ton traveller would have a 4-ton or 5-ton auxiliary. A 40-ton one might have from a 5 to a 10-ton auxiliary.

The introduction of the electric drive has rendered the fitting of auxiliary hoists easy. It was rare to find anything of this kind attempted in the pre-electric days, though the fitting of a separate quick hoist on both hand and steam cranes was and is done. Cranes which are gear-driven, no matter what the source of power; steam, or single motor, are not economically suited for the introduction of very wide ranges of speeds. But the separate motor system is, because when each movement has its own motor, the latter can be selected absolutely for its work. Typical illustrations of the powers, &c., of an overhead travelling crane with auxiliary hoist will be found under **Electric Travellers.**

Auxiliary Machinery.—Under this general head are included quantities of machinery much of which has received its most important developments in recent years. It is not the same thing as Auxiliary Parts, or **Spare Parts,** or replace parts, the object of which is to replace immediately certain sectional portions of machinery which are the most liable to wear or to fracture. Neither is it the same as **Duplicate Machinery,** which is an exact repetition of other machinery to be run, and used in case of a breakdown of the other set which is running, or which is kept to be run alternately with it.

The most important section of auxiliary machines is that which is required for the operation of big power plant, chiefly steam, and principally that on board ship in connection with engines and boilers. It also includes machinery outside this, as winches, cranes, pumps, and properly the machinery for electric light installation, and for steering gear. It is therefore a very comprehensive classification, including all the machinery on board ship except the main engines and boilers.

Beginning with the main engines, we have the mechanisms adopted for turning, and for reversing the engines. Both hand and steam power mechanisms of these kinds are fitted to main engines, the former being only serviceable in those of medium dimensions, such as those of torpedo boat destroyers. *See* **Barring Engines.**

Reversing Engines are necessary because of the great mass of the motion arrangements, and the need of a rapid movement. It is necessary that a marine engine should be capable of reversal from full speed ahead to full speed astern in about twenty-five seconds.

An **Assistant Cylinder** is used to balance the dead weight of massive slide valves, their inertia and friction.

Air Pumps are classed as auxiliary machinery. So are the circulating pumps for the condenser water. Condensers are auxiliary mechanisms. So are boiler feed pumps, and feed water heaters. Ash hoisting engines become a necessity. Filters for feed water are also included. The machinery for steering gear has grown into great importance with the increasing dimensions of vessels. Evaporators to provide fresh water are essential. Refrigerating machinery is used on all ocean vessels that carry passengers, and on battleships, and food-carrying cargo vessels. All these will be found under their suitable headings.

Auxiliary Parts.—This is not used in the same sense as auxiliary machinery, but it has the same significance as spare gear, or **Spare Parts.**

Averaging.—In making estimates and calculations in offices and shops, the practice of averaging various factors saves a great deal of time. Often there is no time for making precise and absolute calculations, and if there were, the results obtained would be no more reliable or valuable than those which are arrived at by men who are accustomed to ready averaging. A few examples will illustrate applications of this method.

Often inquiries come in for tenders for motors or machines, for which estimates are

desired the same night, or next day, or in the course of a week. Now to estimate all the strains and stresses, in order to arrive at correct sections, and to estimate also the amount of materials, and time costs on a biggish job with absolute or scientific precision is impossible in the time allowed. And even if the attempt were made to do so with unlimited time at disposal, the writer's experience is that such estimates are not so safe as those more roughly made by men who are accustomed to prepare them at short notice. There are several reasons for this, but the principal is, that aptitude is acquired in averaging, whereas very much minute detail is liable to lead to the omission of important working factors. Short cuts leave the brain more capable of grasping the broad elements involved. Instead of wasting time, for example, in reckoning things tediously into places of decimals, the mind is content with the integers, and occupies itself more with the allowances that may have to be made for the thousand incalculable things that arise in the behaviour of materials, machines, and men, and which are always modifying the best laid calculations.

The experienced man will average the area and thickness of castings instead of working over them as a land surveyor would an estate, knowing full well that exact estimates are not possible. He will not reckon the heads of bolts and rivets separately from shanks, but average so much per foot of length. Rough allowances will be made for pipe flanges and sockets, also in terms of the length of straight pipe body, and so on in all classes of materials. Time costs, excepting in work that is wholly specialised, can only be averaged, for not only will this depend on differences in men, machines, and methods, but bad work must have some allowance made for it.

Averaging is used in another sense by the liner-out. It denotes the making of less or greater allowances on certain parts than would be made, but for the influences of the allowances available on adjacent or related parts. Thus, if an $\frac{1}{8}$ inch is the regular or intended allowance in all sections for boring, turning, planing, &c., it may be necessary to allow actually $\frac{1}{16}$ on some, and $\frac{3}{16}$ on others. This is due to inaccuracies in patterns, castings, and forgings, by which the relations of parts are rendered slightly different from those intended.

Avoirdupois.—Derived from Fr. *avoirs*, goods or chattels, and *poids*, weight. The measure used for weighing all goods except medicines, gold, silver, and precious stones.

Table of Avoirdupois.

16 Drachms - -	1 Ounce - -	1 oz.
16 Ounces - -	1 Pound - -	1 lb.
28 Pounds - -	1 Quarter - -	1 qr.
4 Quarters - -	1 Hundredweight	1 cwt.
20 Hundredweights	1 Ton - -	1 ton.

The following table shows the mutual relations between the various units :—

Drachms.	Ounces.	Pounds.	Quarters.	Hundredweights.	Tons.
16	1				
256	16	1			
7,168	448	28	1		
28,672	1,792	112	4	1	
573,440	35,840	2,240	80	20	1

The Cental, or New Hundredweight, worth 100 lb., and the half Cental, 50 lb., are also legalised weights, but are used more widely in the United States. 14 lb. is generally reckoned as a stone, but in various trades and markets the stone varies between 8 and 20 lb. The Metric system is far superior to our irrational and cumbrous measures of weight, and to a greater or less extent British trade has suffered through clinging to this system. British consuls have repeatedly deplored the fact that manufacturers have sent out catalogues and quotations in which weights and measures have been set down in tons, cwts., &c., a system quite unintelligible to those nations which have adopted the Metric system. The following tables show the relation between Metric weights and Avoirdupois weights :—

	Avoirdupois.
1 Milligramme ($\frac{1}{1000}$ grm.) -	0·015 grain
1 Centigramme ($\frac{1}{100}$ grm.) -	0·154 „
1 Decigramme ($\frac{1}{10}$ grm.) -	1·543 grains
1 Gramme (1 gr.) - - -	15·432 „
1 Dekagramme (10 grm.) -	5·644 drachms
1 Hectogramme (100 grm.) -	3·527 ounces
1 Kilogramme (1,000 grm.) -	2·204 lb.
1 Quintal (100 kilog.) - -	1·968 cwt.
1 Tonne (1,000 kilog.) -	2204·62 lb., or 19·684 cwt., or ·9842 ton.

The following table shows the metric value of the English measures of weight:—

Name.	Gramme.	Kilogramme.	Tonne.
1 Grain -	·064		
1 Ounce -	28·35	·028	
1 Pound -	453·59	·4535	·0004
1 Hundred-weight -	50802·34	50·8	·0508
1 Ton -		1016·0	1·016

The following commercial terms are used in connection with Avoirdupois weight. *Tare* is a deduction for the weight of the box, case, bag, &c., in which goods are packed. It is "real" when the exact weight of the package is known, "average" when estimated from similar packages, and "customary" when based on a regular tariff. *Tret* is an allowance for dirt, waste, or deterioration in transit, and is generally 4 lb. in 104 lb. With more rapid means of transit this practice is less usual than formerly. The *gross* weight of any merchandise includes the case, receptacle, bag, &c., in which it is contained. The *net* weight is that which remains after "tare" and "tret" have been deducted.

Axe.—This doubly bevelled tool is well known. Its two methods of application are illustrated in the article **Angles of Cutting Tools**. It occurs in two well-known forms,—the English, and the American pattern, the shapes of the heads and the handles being different in each.

Axial Flow Turbine.—A turbine in which the water enters the blades in a direction parallel with the axis. *See* **Turbines**.

Axial Pitch.—Denotes the pitch of screw gears, which is measured parallel with the axis of the gears. The terms "total," and "primary" are applied to this measurement. It is also often stated as the "lead" of the screw. It denotes the length as stated above of one complete turn of a screw thread, of which one spiral tooth is a short section only. If a screw wheel has twelve teeth, then those teeth form short sections of twelve spirals having the same axial pitch.

Axial pitch enters into the calculations for cutting the teeth of spiral gears on the milling machine, and in the lathe when they are so done. It corresponds exactly with the length that would be traversed by the work table (or the tool) during one exact revolution of the blank being cut. The length (or depth) of the wheel being cut is of no moment as far as calculation is concerned, but only the length of the axial pitch of the screw of which its teeth form sections. The length of the axial pitch, the diameter of the pitch circle, and the angle of the spiral tooth are all therefore related, and from either two the third can be deduced either by a diagram, or by trigonometrical calculations. Related to these also are the divided axial pitch, the circular pitch, and the normal pitch. The first named is the pitch of successive teeth taken along the axial line, the second that of the teeth taken round the pitch circumference, and the third that measured normally to the tooth spirals. Each has to be known in designing gears, information respecting the application of which will be found under **Helical Gears, Screw Gears**, and **Worm Gears**.

Axiom.—An axiom is a self-evident truth, a proposition so simple that the understanding must immediately recognise it as true, and accept it as a basis of reasoning. The three primary laws of thought, for example, are axioms:—"Whatever is, is." "Nothing can both be, and not be." "Everything must either be, or not be." Every science must necessarily be based on certain axioms or fundamental propositions which form, as it were, the groundwork on which that science has been built up.

Euclid has based the whole of geometry on twelve axioms :—

1. Things which are equal to the same thing are equal to one another.

2. If equals be added to equals the wholes are equal.

3. If equals be taken from equals the remainders are equal.

4. If equals be added to unequals the wholes are unequal.

5. If equals be taken from unequals the remainders are unequal.

6. Things which are double of the same thing are equal to one another.

7. Things which are halves of the same thing are equal to one another.

8. Magnitudes which coincide with one another, that is, which exactly fill the same space, are equal to one another.

9. The whole is greater than its part.

10. Two straight lines cannot enclose a space.

11. All right angles are equal to one another.

12. If a straight line meet two straight lines, so as to make the two interior angles on the same side of it taken together less than two right angles, these straight lines, being continually produced, shall at length meet on that side on which are the angles which are less than two right angles.

Axis.—This term has numerous significations. Its primary meaning is the centre about which a body moves or revolves. "Centre," and "axis" are terms often used loosely to denote the same thing, but in strictness a centre is a point, and an axis a line. Any point in an axis is a centre of the plane section taken perpendicular to the axis at that point.

It is not necessary to restrict motion to a circular plane in the definition of an axis. Any body having a movement of any kind may be considered as having at any instant a movement about an axis or a centre. This is termed the virtual axis. or the instantaneous centre. It has its application in many elementary mechanisms, in toothed gears, parallel motions, links, &c.

In some calculations an imaginary axis is assumed, or an imaginary radius. It is convenient sometimes to assume an infinite radius to explain linear motion. Angular velocity and linear velocity can thus be expressed in similar terms.

The term axis also denotes the line or plane which divides certain geometric figures equally, as the axis of a circle, a globe, an ellipse, a parabola, or hyperbola, and around which the figure is developed, and which is one of the measurements in calculations relating to such figures.

The axis or plane around which a symmetrical body is developed contains the centre of gravity of the body. In calculations relating to bending moments, the neutral axis is that plane along which neither extension nor compression takes place.

Axle.—The distinction between an axle, a shaft, and a spindle is rather arbitrary. But no trouble arises in their practical applications.

Speaking generally, the term axle is restricted to locomotive, and wagon, and carriage work, and rolling stock of any kind; shaft, or shafting to line, and countershafts; and to any heavy, or medium-heavy rotating axles used on general mechanism, as that of cranes, machine tools, and machines of nearly all kinds. The term spindle denotes in strictness something of relatively small diameter, besides which custom has applied the term to certain shafts or axles, having specific functions, as the spindles of lathes, of drilling machines, and others. In these cases the term is commonly a synonym for mandrel.

An axle is a straight piece of shaft, though this does not mean that its diameters may not vary in journals and shaft, but distinguishes the straight from the cranked axle, which gives rise to problems of a different kind from the straight type. Actually railway axles are never made straight now, because that form would be too rigid. Many years ago as the result of an accident, followed by a Board of Trade inquiry, the modifications were made in the proportions of axles which are in all essentials retained still, Fig. 1. Previous to that the diameter just behind the wheel bed was made larger than that at the journal. The result was that fracture occurred in the wheel bed, where it was concealed from view. Now axles are as large in the beds as behind them, with the result that incipient fractures can

be detected by inspection. Risk of fracture is lessened by making the diameter smaller towards the middle, because this provides enough elasticity to diminish the jarring action that results from the stresses on the axle, which are both vertical, due to the vertical pressures, and horizontal arising from the lateral pressures of the wheel flanges against the rails. The effect of reducing the diameter of the axle is to cause the greatest bending moment to occur just behind the wheel bed, where the fracture would be detected.

This is not saying that axles should be flexible, though this construction has sometimes been put upon it. It is well to mention and guard against this error. The design of axle is adopted with the deliberate object of making one section weaker than another, so that when fracture does occur, as it must sometimes, the fracture will be in the locality open to observation, instead of being concealed by the wheel boss. But within this design, rigidity must be embodied, for otherwise the alternate tensile and compressive stresses which result from flexibility would produce the worst form of stresses, terminating in fatigue and deterioration, the development and extension of hidden flaws. Besides this, bending would result in the wheels spreading.

The dimensions of the bearing necks, or journals of axles are proportioned to the horizontal area of bearing surface. The length of bearing is made about twice the diameter. The load is taken either on the horizontal area of the journal, that is on the diameter, or on the chord of the bearing or step. In the first case a pressure approximately of 300 lb. per square inch of area is taken, in the second one of about 224 lb. per square inch. This gives 10 square inches of bearing area per ton load.

The life of axles has often been discussed, and figures given for those of wrought iron and steel. There is no difficulty in obtaining data for locos, but there is for wagons, and particularly for those belonging to private owners. The average life of locomotive axles is taken at about 220,000 miles, that of wagon axles at about 94,000 miles. This average is often greatly exceeded in individual cases, wagon axles sometimes exceeding 200,000 miles. From ten to twelve years is the average life, measured by time, though many run from twenty to thirty years. 280 tons is the average weight per annum carried per axle by the wagon axles of the United Kingdom, exclusive of the weight of the vehicle.

Data are not easily obtainable for the total number of railway axles running in the world. Mr T. Andrews estimated that at the end of 1891 there were 5,775,843 running, a number which must be considerably exceeded now.

Hollow Axles.—If a hollow axle can be made rigid, it has some advantages over a solid one. The practice has been adopted to a limited extent for a number of years. These have been made by casting hollow, by forging round a mandrel, and by boring out of the solid metal. They have been made hollow throughout, and hollow for a portion of the way only in from each end, extending a little beyond the wheel boss. The best design is that in which the holes are punched, thus leaving the smaller middle portion solid. Hollow axles have had but a limited use, partly on the score of their cost, partly because few have been entirely satisfactory under test, and in service. Yet a properly made axle of this type should be better than a solid one, for the same reason that a hollow ingot, or a hollow column, or a hollow propeller shaft, or crankshaft is preferable to solid articles. The middle section, so often spongy, and always of coarser, more open grain than the outer layer, is thus removed. This is the principal advantage. Lesser ones are, that weight is reduced, though very much stress is not to be laid on this, but the saving in steel—say about 33 per cent.—is considerable. In the case of axles that are not hollow throughout, the ends can be utilised as oil chambers. The other advantages claimed are those due to the processes involved in the manufacture,

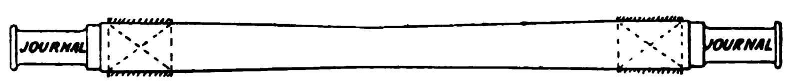


Fig. 1.—Standard Axle.

by virtue of which the material is compressed, and rendered more homogeneous, with the benefits that result therefrom. The evil to be guarded against is getting the metal too thin at the journals, by reason of which many of the earlier axles failed. This was the cause of failure of axles of this kind, made in 1869 for the Dublin to Cork Railway, and in 1870 for ore trucks for Ebbw Vale.

The formation of the holes by punching appears to have been due to Erhardt, 1891-2, first used at Düsseldorf. The holes were made right through, by a long punch, while the solid bar was confined in a mould. These axles were stronger than solid ones, but their high price was prohibitive. A system is in use at the Homestead Steel Works of the Carnegie Steel Co., by which railway axles are pressed on a large scale by means of punches from each end leaving a central solid portion, Fig. 2. The method is briefly as follows:—

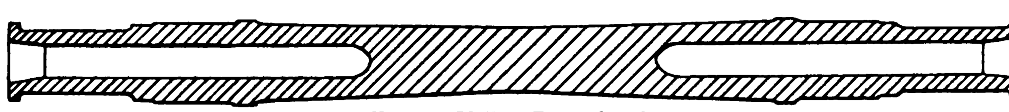


Fig. 2.—Hollow Pressed Axle.

A steel blank, rolled round, and heated to about 1,000° or 1,050° Cent., is placed in a die, having the sectional shape of an axle, and the ends punched simultaneously, Fig. 3. The formation of the holes also has the effect of pressing out the metal to fill the enlarged portion of the dies. The total hydraulic pressure required, using a 3-inch punch, is 50 tons at the start and about 150 tons at the finish, due to the cooling of the metal, and the upsetting of the end collars. Under these pressures the metal flows and fills up the enlarged portions. The punch being tapered, acts as a wedge, and the pressure produces homogeneity. The journal surfaces are capable of receiving a high polish. No straightening is required, and the cost of cutting ends and centring as done on solid axles is saved. A tough skin is formed in the interior, which remains, and tends to increase the stiffness of the axle.

The temperature named above is found to have a most important effect on the results. The minimum practicable is given as 850° Cent., but at this heat an initial punching pressure of about 250 tons is required, and a final pressure of 500 tons. Tests on an axle punched at 1,050° Cent. are given below (many of the blows are omitted). The Pennsylvania Railroad drop test specifications were followed, viz., seven blows at 43 feet, of 1,640 lb. weight, striking midway between supports 3 feet apart, axles to be turned over after every other blow. The axles, having stood this test, were subjected to further blows until destruction.

Number of Blow.	Deflection (in.).
1	$3\frac{7}{8}$
7	$3\frac{1}{16}$ (fulfilling test).
14	$4\frac{9}{16}$
21	3
28	$4\frac{9}{16}$
35	$3\frac{1}{8}$
37	Broke in centre.

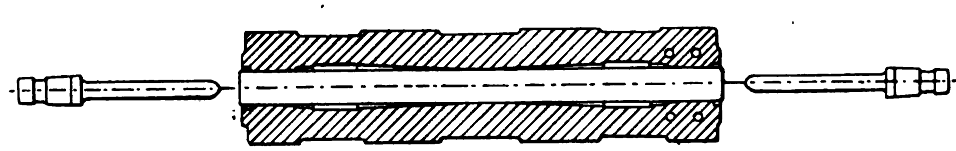


Fig. 3.—Punches about to operate.

The description and illustration of the press used in this work would be too lengthy for the purposes of this article. The method of attachment of a punch to its ram is shown in Fig. 4. As the length of the punch is eight times its diameter, which is in excess of that desirable for cast iron, hard Bessemer steel, containing about 0·1 per cent. of carbon, is found to give the requisite stiffness. Steel caps are fitted to form the effective points of

the punches. They are a little larger than the punch body, to avoid excessive friction between the latter and the hole. They are renewed for each axle. The punches are blackleaded. It is necessary to punch rapidly to prevent them from overheating. The time occupied in making an axle does not exceed two minutes. Another two minutes is occupied in cleaning and black-leading the dies, and for cooling and refitting caps to the punches. One press will thus turn out fifteen axles per hour. The hollow axle holds its own oil, *see* Fig. 5, showing a section through axle journal and box.

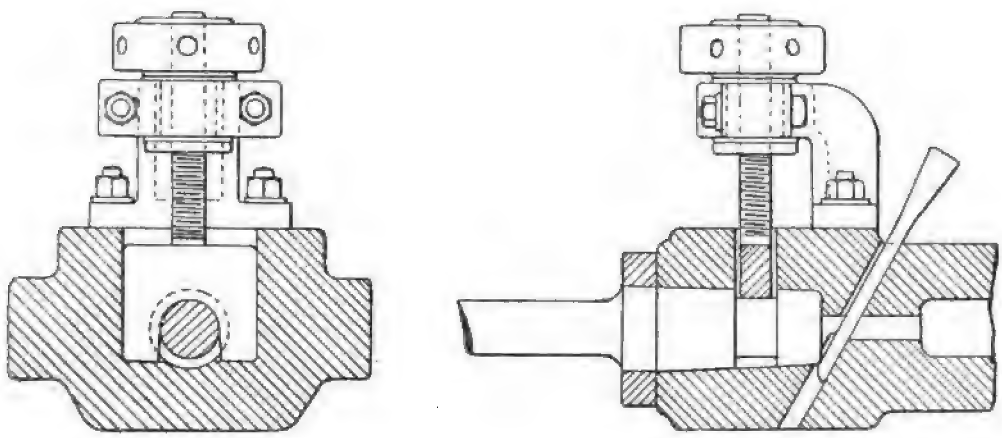


Fig. 4.—Method of Attachment of Punch to Ram.

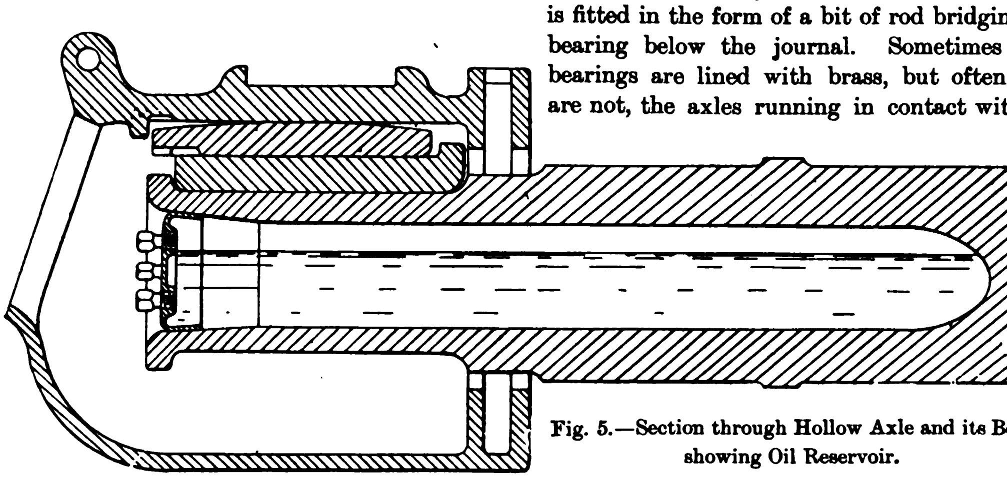


Fig. 5.—Section through Hollow Axle and its Box, showing Oil Reservoir.

Axle Bearing.—An axle bearing may be the bearing portion of an axle box, or an entire bearing which is not a box. The term may also denote the bearing area between the axle journal and its bearing.

A common form of axle bearing is that in which a simple concavity, without any keep or cap, receives the pressure of the journals. These are used on many trolleys for narrow gauge tracks, and on skips. The absence of keeps or caps does not matter, because the load maintains the bearings in contact with the upper part of the journals. Sometimes a keep is fitted in the form of a bit of rod bridging the bearing below the journal. Sometimes such bearings are lined with brass, but often they are not, the axles running in contact with the iron. A little play is allowed, and the bearings are not tooled, but simply smoothed by grinding over a cylindrical emery wheel. Lubrication is done through a tube with oil. Or a receptacle is cast to one side to receive grease.

Axle Box. — An axle box is a type of

bearing that stands alone in its design. The first feature by which it is distinguished is the element of "play" between the journal and its bearing. The latter never makes a close fit round the journal in either direction, but both side and end play are allowed. This is rendered necessary by the movements of heavy rolling stock at high speeds, which, without such play would cause the bearings to become heated, or the boxes to be knocked to pieces. The bearings and the springs through which the pressure is transmitted to the frames are elastic and accommodating in vertical and horizontal directions. Absolute continuous contact is only provided for at the crown of the step, with which the upper part of the box is lined, and this is the bearing around which the remainder of the box is designed. But this simple little step has been the subject of innumerable experiments, and in its form, method of fitting, and materials, only a small selection of which is given in the accompanying figures.

Gun-metal, brass, and phosphor bronze in many grades of composition have been used for steps, and tables innumerable record the results obtained with different alloys. Rivals to these are the white metals, used as linings to a harder alloy, or as separate anti-friction surfaces, obtained by drilling holes in the bronze and filling them with the white alloy. Different railways use different compositions, and various designs of boxes, some of which are here shown.

Axle boxes may be grouped under two main types, the locomotive, and the carriage. Underneath the journal in engine axle boxes is the keep, a casting which fits between the sides of the boxes, and prevents much vertical movement between the journal and its step. It is hollowed to fit the curve of the journal, but is in no sense a bearing, as no working pressure ever comes upon it. Frequently, as in wagon boxes, there is no keep fitted, beyond the hole through which the axle enters the box, and the piece of wood which is inserted to prevent the entry of dust. The designs of the outer boxes vary, according to whether the axles go right through, as in outside wheels, or whether they are entirely enclosed, as in inside wheel arrangements, and in wagons. In the latter case a hinged or pivoted cover is fitted in front (*see* Figs. 10, 12), and this is made the medium for receiving the monogram of the company. Another modification is made by the methods of lubrication adopted, whether oil or grease. In the first case a pad or wad is fitted in the lower part of the box, in the keep. These pads comprise various arrangements of tapes by means of which the oil is carried up to the journal (*see* Fig. 6). If grease is used, it is introduced into a box above, and is melted by the slight warmth of the journal. Oil is, however, frequently used in this form of box.

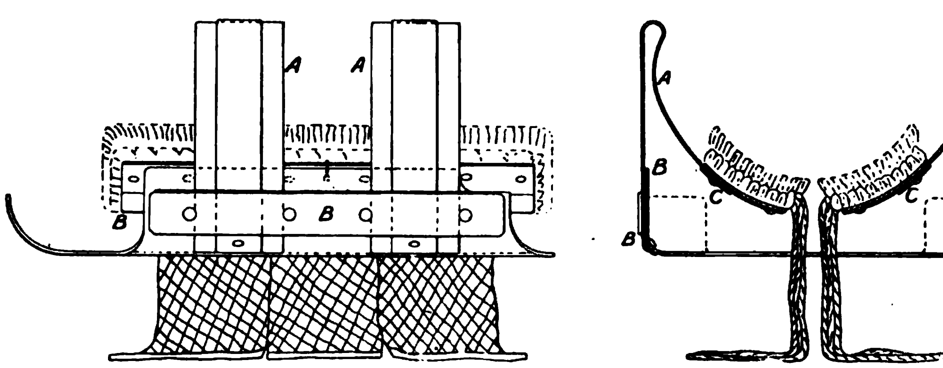


Fig. 6.—Axle Wad, or Pad—Midland Railway Wagon.

A. **Steel Spring.** *B.* **Leather.** *C.* **Strap Plates.**

Axle boxes are not rigidly fixed, for reasons just now given in relation to journal contact. They are free to slide vertically, either in the horn blocks, or the axle slides. The difference between the two is that the first is a continuous

casting bolted against the horn plate, or main frames, and that the second is in the form of strips bolted against the plates. The springs above or below afford the necessary elastic resistance to the vertical movements of the boxes. The grooves on the outsides of the axle boxes

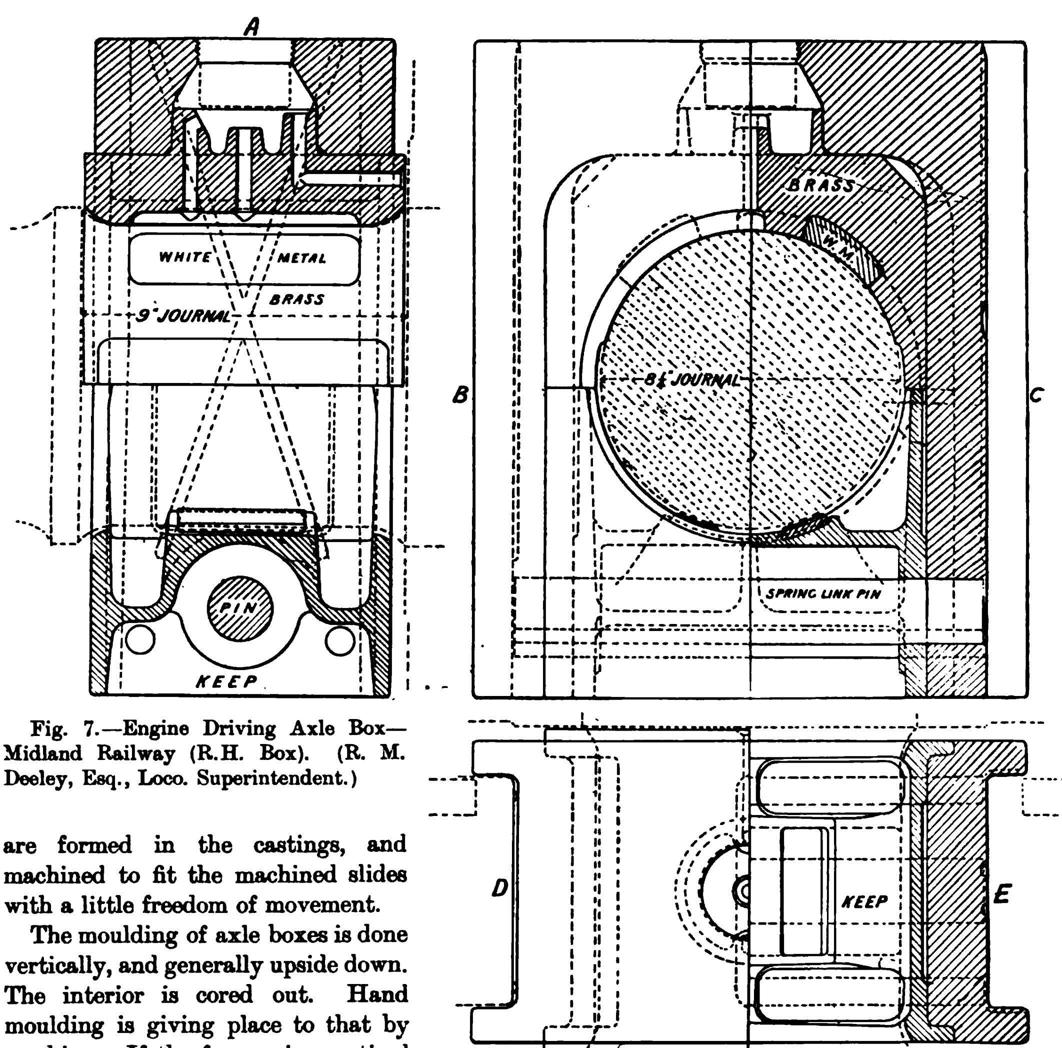


Fig. 7.—Engine Driving Axle Box—Midland Railway (R.H. Box). (R. M. Deeley, Esq., Loco. Superintendent.)

are formed in the castings, and machined to fit the machined slides with a little freedom of movement.

The moulding of axle boxes is done vertically, and generally upside down. The interior is cored out. Hand moulding is giving place to that by machine. If the former is practised much economy is obtainable by plating the pattern, and fitting special boxes to the plate. But this gives no advantage in the lifting, which is done much better by machine, being perpendicular and steady. There is no advantage in the ramming, which is done by hand in each case, the depth being too great to admit of sound and even power ramming. Steps, doors, and covers are plated, two or more on a plate, and these can be rammed as well as moulded by power.

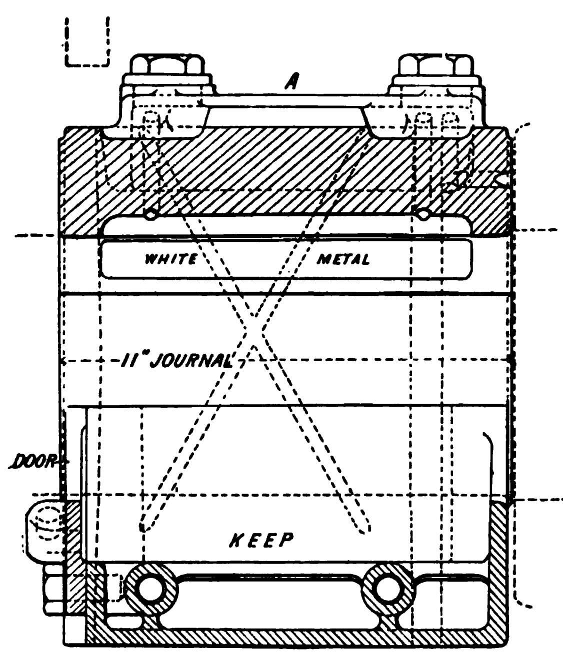
The machining of axle boxes is done by planing, or milling, or grinding, or all are utilised. The concavity of the step only needs to be smoothed by grinding. The grooves for the slides can be milled, or planed in a row, the former being now generally preferable.

Description of Boxes.

Midland Driving Axle Box.—The views of these, Fig. 7, are as follows:—The top left-

hand figure A is a vertical section taken in the longitudinal direction of the axle, the half-view B is an external one of the box, the half-view C is a transverse section, the half-plan D is looking on the box, and E is a sectional plan looking in the keep. This box receives a brass bearing above, recessed for liners of white metal. The brass is provided with flanges, no other fitting being required. The lower part of the box is occupied by a keep which has steps of white metal inserted. The spring link pin, 1¾ inch diameter, potash hardened, passes through the keep. The central lubricating channel in the brass, and the oil cup, and oil holes are shown, as are also the diagonal oil channels for lubricating the surfaces of the axle box and its guides.

Midland Engine Bogie Axle Box (Fig. 8).—The three views are as follows:—A to the left is a vertical section through the centre of the box, taken in the longitudinal centre, the journal, 11 inches long, being indicated. Views B, C are taken one-half, B, outside the box, the other, C, through the centre. B, however, shows an oil cup and cover in section. The oil runs down into a channel going nearly the whole length of the bearing, seen in all the views. The step in this design is solid with the box, but is lined with anti-friction metal in two dovetailed recesses seen clearly in the views A, B, C. The keep is seen below, with its bosses and bolt holes, and the door with its filling hole, and stud bolt. The two views D, E in the lower right-hand



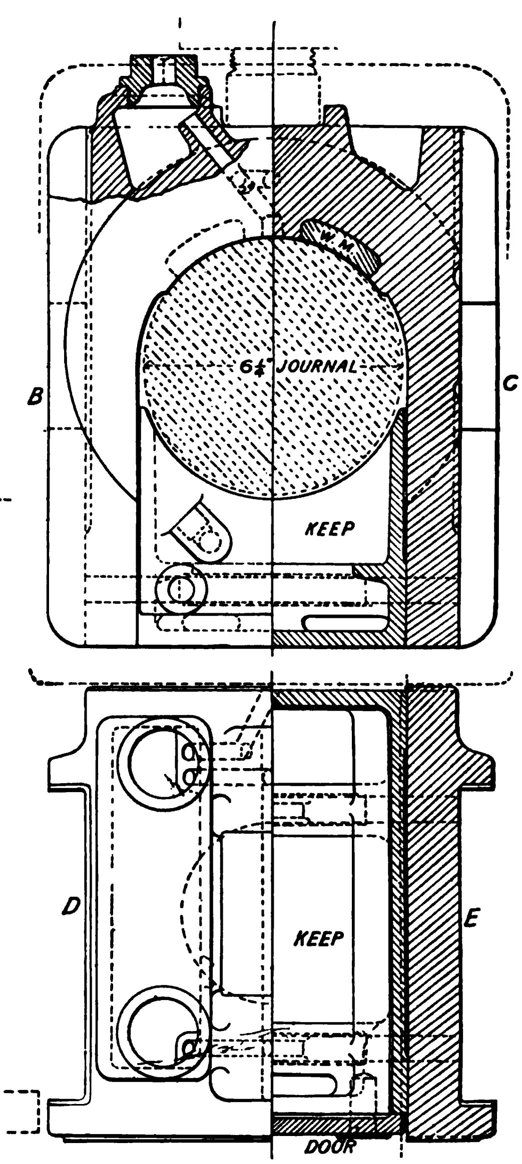


Fig. 8.—Engine Bogie Axle Box—Midland Railway (R.H. Leading Box). (R. M. Deeley, Esq., Loco. Superintendent.)

figure are respectively external half-plan, and sectional half-plan, taken just through the keep door. Diagonal oil grooves for the faces which bear against the axle slides are seen in the view A, and indicated in section in C, and E. The spring pin is indicated above.

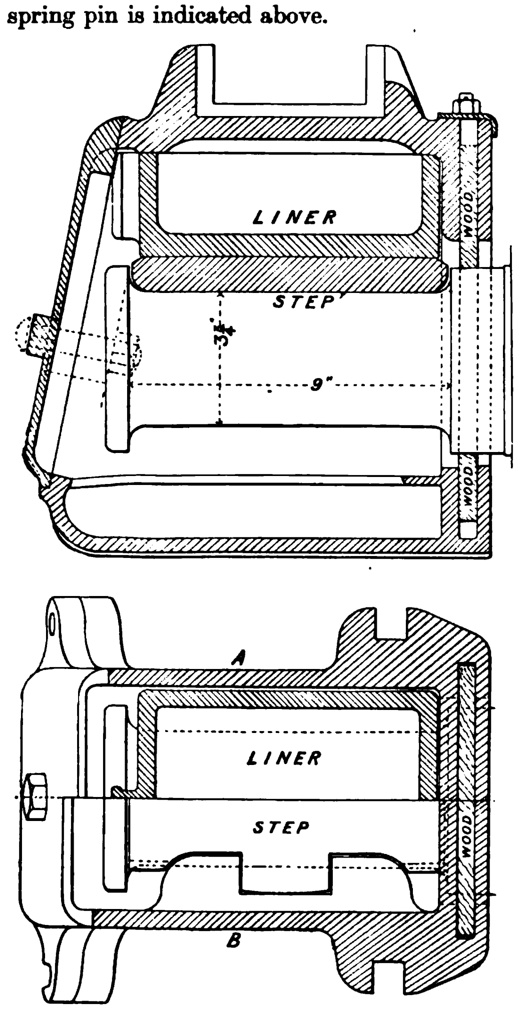


Fig. 9.—Oil Axle Box for 10-ton Wagons. Midland Railway (D. Bain, Esq., Superintendent, Carriage and Wagon Department).

Midland Wagon Axle Box.—Fig. 9 gives two sections through a Midland Railway wagon oil axle box for 10-ton wagons. The upper view is a vertical longitudinal section, the lower one, half sectional plans, taken through the liner in the half A, and with the liner removed in the half B. The liner fits loosely within the upper part of the axle box. The brass step or pad is retained between the face of the liner and the axle by shoulders on the interior of the axle box, which are precisely like those shown in the bogie axle box in Fig. 10. It is retained from slip in the longitudinal direction by the shoulder seen in the plan at side B, Fig. 9. The loose fitting and convex edge there shown, with the loose fitting of the liner permit of accommodation of the bearing to the irregular movements of the axle. The wood packing or wad prevents access of dust to the journal.

Bogie Axle Box.—The box for a bogie carriage, Fig. 10, has a general resemblance to the ordinary axle box for wagons. The fitting of its liner is similar, but the brass step is lined with white metal $\frac{1}{8}$ inch thick. The details are apparent, following the description of the previous box. In Fig. 10, A is a longitudinal section, B a face view with the door removed, and C a transverse section. The fitting of the liner and step in plan is like that in A, B, in the previous figure.

Standard Wagon Axle Box.—This, Fig. 11, differs from the previous examples in the fitting of the step-bearing, method of lubrication, and some lesser details. The type is common. The step is of brass, and is retained by means of wing lugs as in previous examples. The bolt supplies a cheap form of keep. The views comprise A, longitudinal and vertical section; B, C, two cross-sections through an oil hole, and through the centre respectively, D external plan, E sectional plan through the axle space, F inverted section looking up at the seating of the brass, with the latter removed. There is a little detail in this to which attention may be called, namely, the casting of two slot-shaped holes, next the guide for the horn blocks, seen in the Figs. D, E, and F. These fulfil one function only, that of ensuring sounder metal in that locality, the slight lessening of weight being of no practical importance. Many cases of this kind are always occurring in foundry practice. If the holes were not made, the casting would certainly draw and be spongy to a greater or less extent in the middle of the thick mass. The alternative is either a good deal of feeding, or taking out the middle of the mass with a core, the latter being preferable.

The Axle Box for the Bogie Horse Box (Fig.

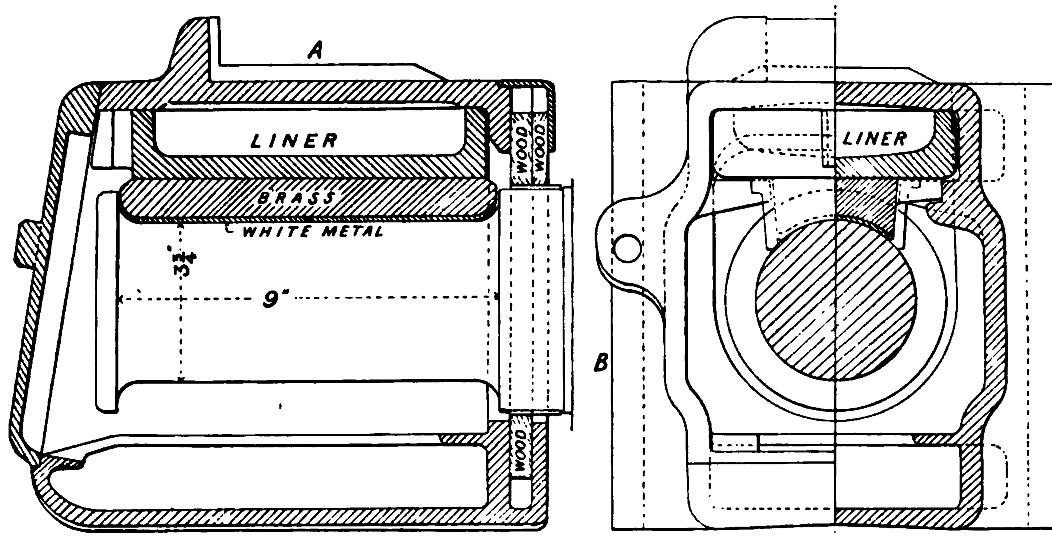


Fig. 10.—Oil Axle Box for Bogie Carriage. Midland Railway.

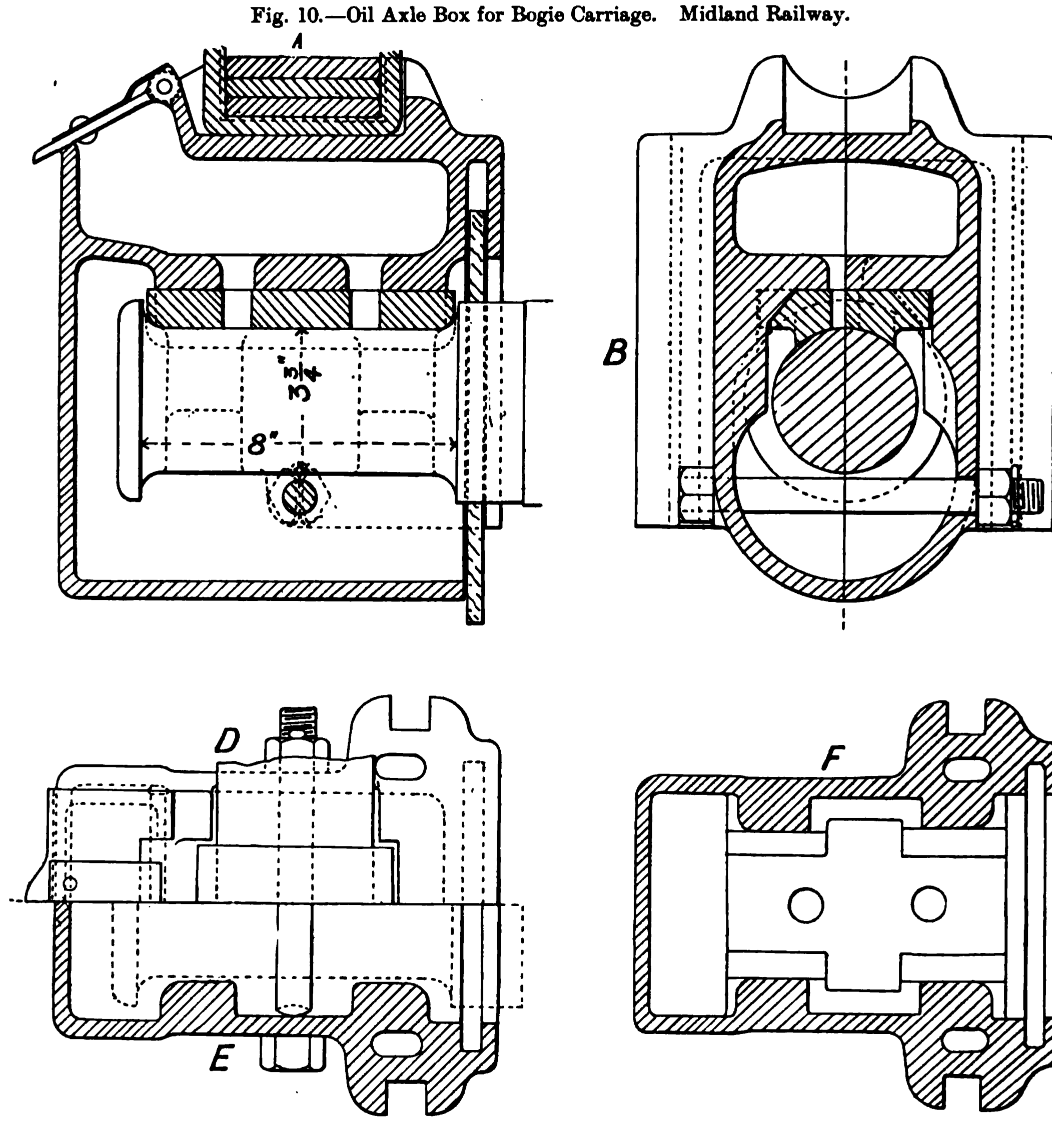


Fig. 11.—Standard Wagon Axle Box. (Gloucester Carriage & Wagon Co., Ltd.)

12) has its bearing-step made of Stone's white bronze. The views are as follows:—A is a vertical longitudinal section, B a transverse section through the timber recess, C a similar section across the box at the centre. D is a plan section, taken just above the journal, E an external plan view, F is a front elevation with than ordinary running, producing severe blows and shocks between the journals and the boxes, with resulting fracture. Cast steel has been used to a considerable extent, but drawing and honeycombing of the castings are liable to occur. About 1890 pressed boxes of mild steel were first manufactured. In these, an example

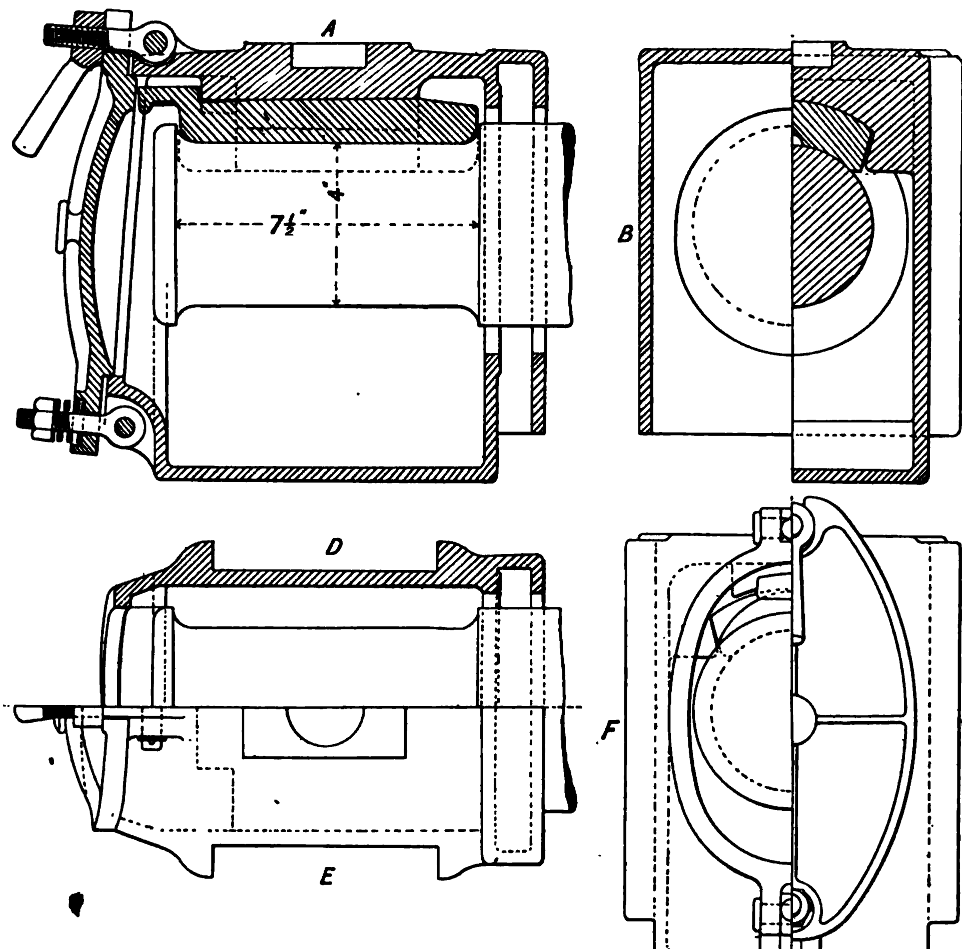


Fig. 12.—Axle Box for Six-Wheeled Car Bogie Horse Box. (Gloucester Carriage & Wagon Co., Ltd.)

the cover or lid removed, and G is a front elevation taken against the cover (seen in section at A).

Pressed Boxes.—Objections to the use of cast iron for axle boxes have always been made. Though the metal is massive, and the flanges well bracketed, boxes frequently break. The effect of sudden jerks in shunting is more severe

of which is shown in Fig. 13, the only casting is the brass step. The steel plate used is about $\frac{1}{4}$ inch thick, with the result that the weight of a box made thus is about two-thirds less than that of cast-iron ones.

As the average weight of a cast axle box is 100 lb., the saving in weight by the substitution of stamped for cast boxes on something

like a million wagons in the United Kingdom, belonging to the railway companies and private traders, would be enormous. Some years ago it was estimated that the cost, direct and indirect, to the railway companies of the Kingdom of damaged axle boxes worked out to something like £170,000 per annum.

Some welding of joints is necessary, as well as stamping, which is done by means of pneumatic hammers, the heat being taken with a gas flame. A difficulty in bending is due to the comparatively sharp angles which occur, and which have to be produced without a reduction of section. A special plant of dies has to be laid down by the manufacturers.

Axle Friction.—*See* **Axle Box**.

Axle Grease.—This is composed of various mixtures of which tallow is the basis, mixed with mineral oil, plumbago, paraffin, and soda.

Axle Grinding Machines.—These are used extensively, supplementing the work of the lathe, or superseding it, and also for correcting the journals of axles that have worn badly. The original grinding of this kind was, and is often now done on a common lathe, having a grinding spindle fixture attached. This receives both traverse and radial feeds from the motions of the rest.

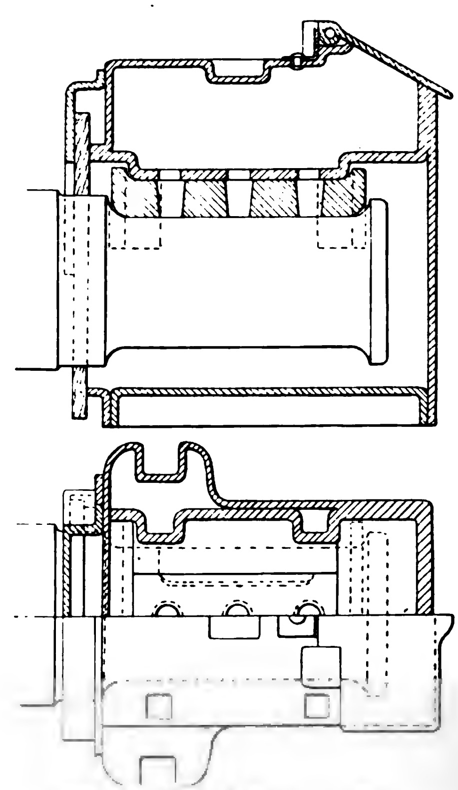


Fig. 13.—Pressed Steel Axle Box.

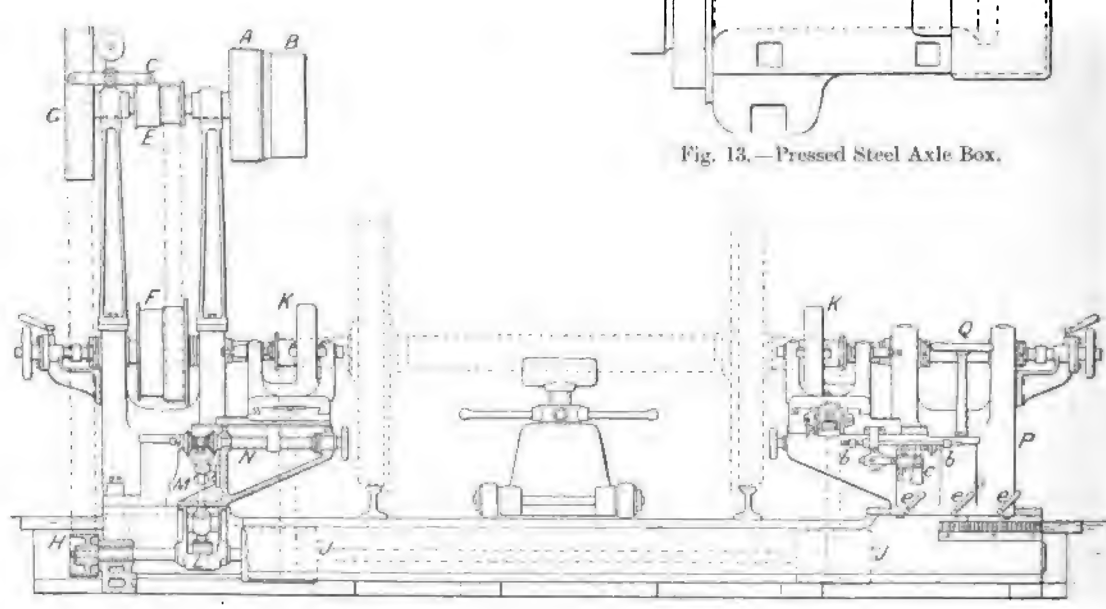


Fig. 14.—Axle Grinding Machine (Front Elevation).

A special form of axle grinder designed for this work alone is illustrated in Figs. 14, 15, by Mr F. Schmaltz, Offenbach-on-Main. Rails are laid on to the machine as shown, and

the wheels with their axle are run upon these, without the assistance of a crane, and the central jack lifts the axle up to the centres, in which position the wheels clear the rails.

The driving is done as follows:—The fast pulley A receives the belt when driving, B being the loose one on which the belt runs slack, and is thus relieved of tension when not in service. The striking gear comprises the lever C pulled by dependent cords, actuating the bar D, and thence the belt fork *a*. By the pulley A the two-stepped cone E is driven, whence the motion of the headstock pulley F

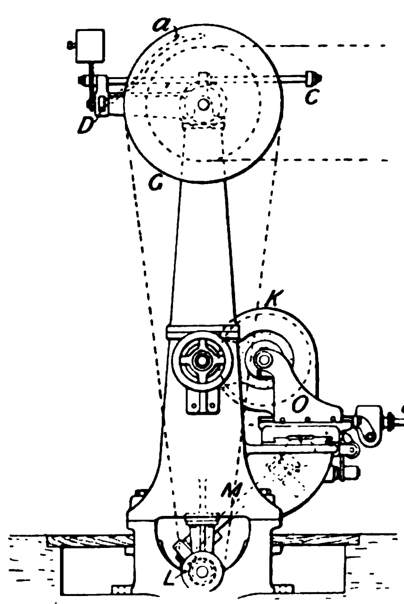


Fig. 15.—Axle Grinding Machine (End Elevation).

is derived. The pulley G, also driven by A, drives H, situated in the base of the machine, which imparts the movements to the emery wheels. It will be noted that the countershaft is carried by uprights bolted to the headstock, so making the machine self-contained.

The pulley H, in the base, drives a shaft which carries two pulleys J J that are belted to pulleys that drive the grinding wheels K K. The same shaft carries worm gears L, which drive diagonal shafts M M, that give motion to nests of bevel gears, with reversing clutches, whence the short traverse screws, one being seen at N, derive their motion, so feeding the wheel heads past

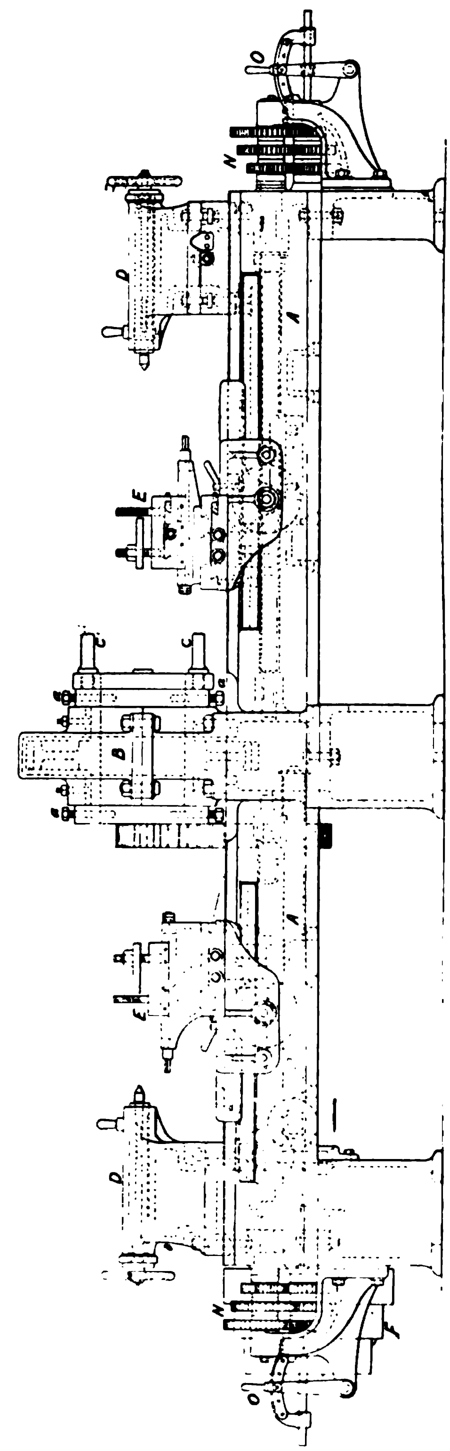


Fig. 16.—Axle Lathe (Front Elevation).

the journals. The feeds are reversed automatically by means of the dogs *b b*, when the lever *c* throws the clutch into engagement with the opposite bevel wheel in the nest of gears.

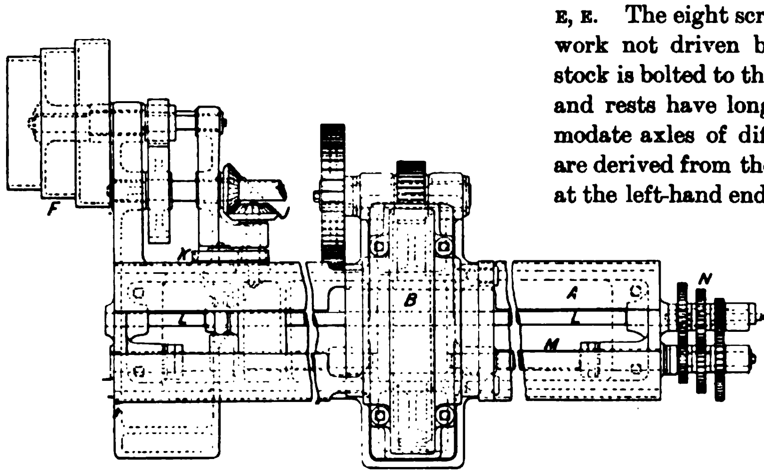


Fig. 17.—Axle Lathe (Plan View).

The radial feed is effected by moving the wheel head O inwards by the spindle *d*, which also has provision for both coarse and fine feeding. The footstock P is capable of a limited amount of adjustment along the bed to take axles which vary in length, being operated by a rack and pinion actuated by the hand wheel Q. It is clamped by the handles *e, e, e*.

Axle Guards.—The horn plates, or slides, between whose faces axle boxes slide.

Axle Keep.—*See* **Axle Box.**

Axle Lathe.—Special lathes for turning railway axles are either single, or double, illustrations of one of the latter being given in succeeding figures, which are detailed drawings of a lathe by Sir W. G. Armstrong, Whitworth, & Co., Ltd., of Manchester. Fig. 16 is a front elevation, Fig. 17 a plan view, with the bed broken, Fig. 18 an end view (enlarged) taken from the left hand, or driving end, Fig. 19 a part plan, and a cross-section (enlarged) taken vertically through the bed in front of the rests, Fig. 20 an end view (enlarged) at the right hand, showing the adjustable poppet and the feed change lever.

The bed A is supported on three standards. The central one is immediately underneath the headstock B, in and by which the axle is driven. The axle runs between centres, and being fitted with carriers, is rotated through the equalising drivers C, C without torsion, and having its journals turned by tools held in the slide rests E, E. The eight screws *a* are only used for short work not driven between centres. The headstock is bolted to the bed, and the movable heads and rests have longitudinal traverses to accommodate axles of different lengths. Movements are derived from the three-stepped cone pulley F, at the left-hand end, driving the shaft G through gears which can be traced out in the end view, Fig. 18, whence the double gear of the fast headstock is operated—the pinion on shaft G driving the wheel H, which forms an integral part of the sleeve revolving within the headstock body B, by which the work is rotated, and to which three primary rates of revolution are imparted by the cones F.

There are two saddles carrying four slide rests,

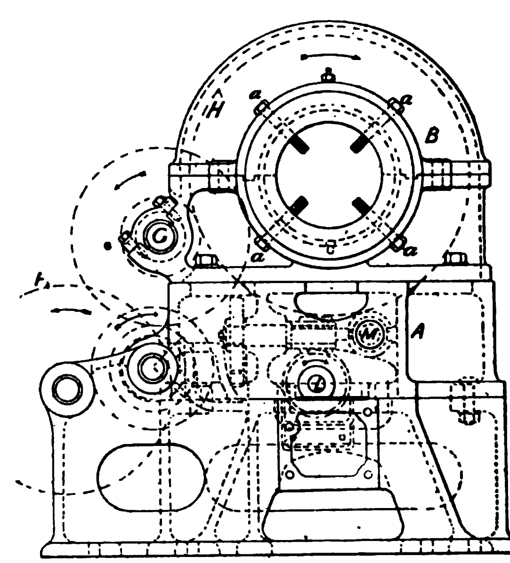
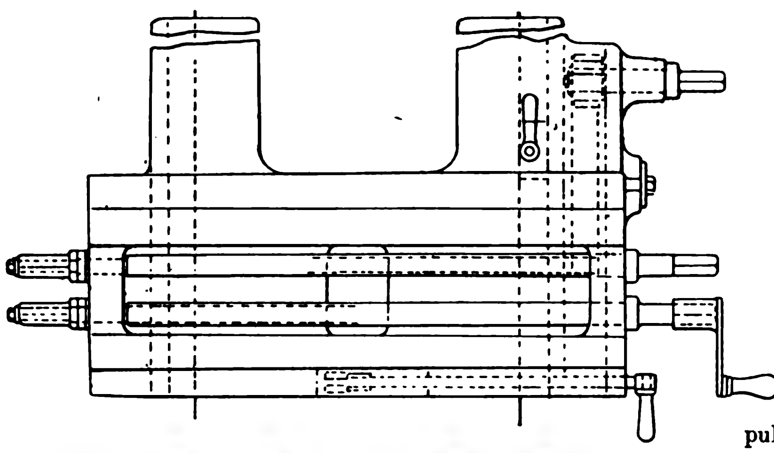


Fig. 18.—Axle Lathe (Rear End View).

E, back and front, as shown in the section, Fig. 19, with their separate operating screws in plan above.

The feeds for the slide rests are derived from



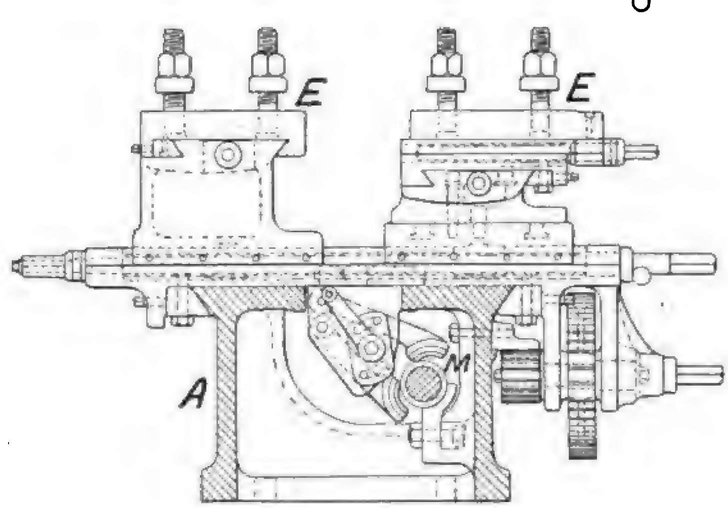


Fig. 19.—Axle Lathe (Cross-Section).

the cones F, in the manner seen in the plan view, Fig. 17, through' spurs, mitres, and spurs again to a worm-driven shaft L, whence the two lead screws M are driven through the permanent gears N at each end of the machine, separately adjusted by means of the levers O, Figs. 16 and 20. The changes give 8, 16, and 32 cuts per inch. The position of the levers O in their quadrant holes determines the amount of feed.

The screws M are right and left-handed, so that the movements of the rests are towards, or away from the centre. Either rest can be instantly disconnected by throwing its clasp-nut out of engagement, Fig. 19. Rapid adjustments of the rests are effected by racks and pinions.

In order to get the axles in and out quickly, the loose headstock at the right-hand end is arranged to move in and out of centres by means of a quick pitch screw (*see* Fig. 20).

The height of centres of this lathe is 12 in., its maximum capacity between centres is 8 ft. 6 in., the hole in the headstock 12 in. diameter. The firm makes another of a lighter build for truing the journals of carriage axles. In this a split pulley grips the axle in the centre, and a belt is put on this, driving a pulley which actuates the feed motion. When turning is being done, a strap is put on one of the wheel tyres to be driven from countershaft, or motor.

Axle Slides.—*See* **Axle Box.**

Axle Springs.—*See* **Springs.**

Axle Wad.—*See* **Axle Box.**

Ayr Stone.—*See* **Hone.**

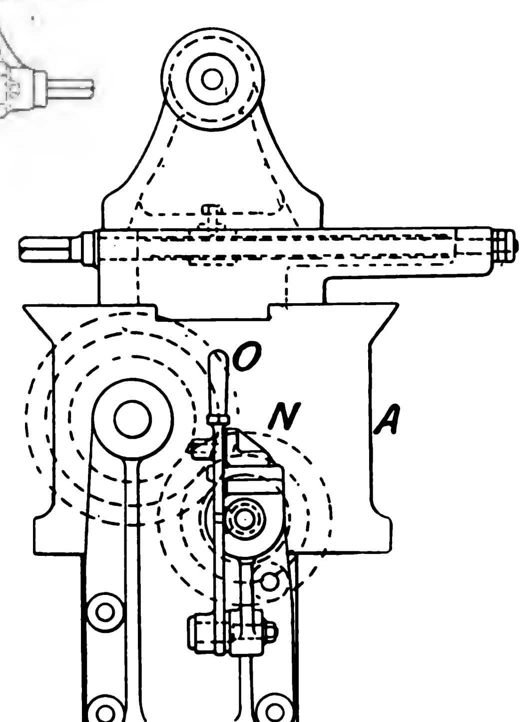


Fig. 20.—Axle Lathe (End View, Right Hand).

B

Babbitting.—Signifies the art of lining bearings with white metal. Holes are sometimes drilled at intervals to receive the lining. But it is more usual to have a continuous lining which is held in various fashions. Another

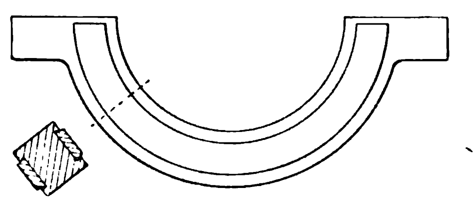


Fig. 21.—Eccentric Strap Lined with Babbitt.

method is to cut dovetailed slots in the bearing to receive and retain the molten alloy. When these are fitted to lathe and machine spindles, the Babbitt is often subjected to compression

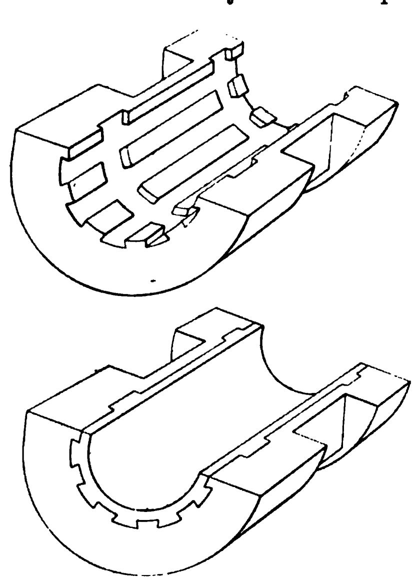


Fig. 22.—Bearing Box Lined with Babbitt.

to make it of very close texture to endure the friction of the spindle longer.

Articles to be lined solidly with Babbitt are tinned first. The portions to which the alloy must not adhere are encased in clay. The part to be tinned is wetted with alcohol, and sprinkled with sal ammoniac. It is heated till fumes arise and then immersed in Banca tin. A former is used to impart the correct shape to the bearing of the lining, the casting is heated to the melting point of the tin, and the Babbitt poured in between the tinned face and the former. Figs. 21 and 22 illustrate respectively an eccentric strap, and a bearing box lined with Babbitt. Sometimes the runner hole, ½-inch or ¾-inch diameter, is made through the box backing, and the metal fed with a wire, but large bearings are stood on end and poured at the top end directly (Fig. 23), without a runner hole, through the space between the shell and the former. The metal is fed as it cools. A rod bent at the end is inserted to scrape the tinned surface, and prevent separation of the Babbitt from that surface by oxidation. Sometimes the whole is enclosed in a moulding box and rammed with sand, when the fit between the former and the box is not sufficiently good to prevent escape of the metal. When cold, a templet block may be hammered on the bearing face

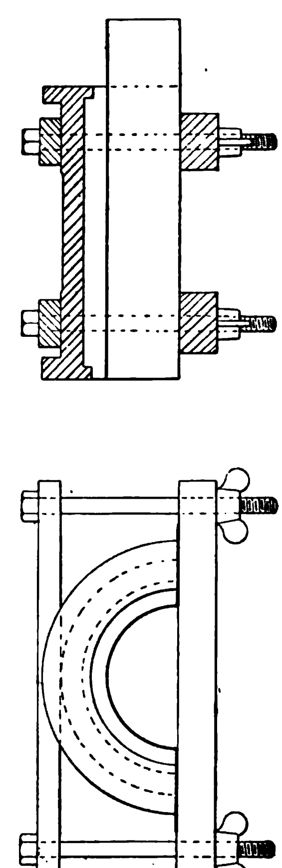


Fig. 23.—Bearing ready for pouring Babbitt.

to render it solid throughout. The lining of Babbitt may be thin or thick. If well supported behind, a thin lining suffices, but a thick one, say from ½ inch to ¾ inch is preferable. By casting on a former or mandrel, boring may often be avoided, with, or without scraping the surface.

Babbitt Metal.—A white anti-friction metal which has been used for many years, and so named after its inventor, Mr Isaac Babbitt, a brassfounder of Boston, U.S.A. It appears that the shell or box was patented, but not the lining metal, which was run into holes countersunk in the box. The original recipe was the following:—4 lb. of copper, 8 lb. of antimony, 24 lb. of tin = 36 lb. This was termed hardening. To every lb. of this mixture 2 lb. of tin was added. Thus, 36 lb. hardening + 36 + 36 lb. tin = 108 lb. of Babbitt. In other words 4 lb. of copper, 8 lb. of antimony, and 96 lb. Banca tin.

In making Babbitt the same precautions must be observed as in other alloys (*see* **Alloys**) which contain constituents having high and low melting points. The melting must be gradual, or the antimony and tin will largely separate from the copper and form oxides or dross on the surface. Thus, 4 lb. of copper are melted first, then 12 lb. of tin, and 8 lb. regulus of antimony are added slowly to the molten copper, to which 12 lb. more of tin are added, to form the hardening. Then for use with each lb. of this, melt 2 lb. of Banca tin. The surface should be covered with charcoal powder, and a small portion of sal ammoniac. Previous to pouring it should be stirred well.

Considerations of cost have resulted in cheaper substitutes for the original mixture, so that the term Babbitt has come to signify a good many different things. But the closer the original is retained the better is the material. A good recipe is 10 parts of tin, 1 copper, and 1 antimony. But some contain lead, which is unsatisfactory. The adulteration with lead in small quantities only is not very objectionable, but the alloy is not genuine. If lead is added to tin, the alloy will mark on paper, and this affords a rough test of the presence of lead. Lead additions permit of producing a cheaper alloy, besides which they render casting easier, and give less trouble in the production of a good surface.

The following are cheap alloys containing lead. Hardening 16 lb., tin 50 lb., antimony 20 lb., lead 80 lb. Hardening 32 lb., tin 64 lb., lead 63 lb. The antimony is added in small pieces, to a portion, say one-half of the molten lead, after which the remaining portion of lead is added. A mixture termed "hard lead," used largely in America for lining the brasses of cars contains, lead 80 lb., antimony 20 lb. This may be improved by adding in varying quantities, as hard lead 100 lb., added tin 100 lb.

The great value of antimony lies in its hardening property. By due proportioning it is practicable to make bearings harder or softer. Neither this metal nor tin are corroded by the acids in oils, and they are for this reason also valuable.

Babcock & Wilcox Boiler.—This belongs to that great group of water-tube boilers, in which the tubes are inclined more nearly to the horizontal than to the vertical, and are thus suitable for ordinary service as distinguished from the later, or "Express" boilers. The tubes are large, and deliver into headers and thence into the drum.

This boiler had a long period of about thirty years of successful land service before it was adopted for ships, on which it has now been fitted in numerous cases, since the first installation in the torpedo gunboat *Sheldrake* in 1898. It is, at the time of writing (May 1905), in use for stationary purposes to the extent of over 4¾ million IHP. in all parts of the world. It has during recent years been developed for marine service in such a satisfactory manner that it has obtained a high record for economy, low cost of maintenance, and general suitability for the requirements of this class. The construction illustrated in Figs. 24-28 is as follows.

It consists in the main of an arrangement of inclined tubes A, forming the bulk of the heating surface; the horizontal steam and water drum B, and the mud drum C. The tubes are expanded at both ends into steel boxes or "headers" of wrought steel, and thus form sections vertically. By means of connections with the steam and water drum at the high ends of these headers, the steam generated in

the tubes is liberated, and the water supplied to take its place. The furnace D is underneath the nest of tubes, and the gases as shown by the directions of the arrows, Fig. 24, come into intimate contact with all the heating surface.

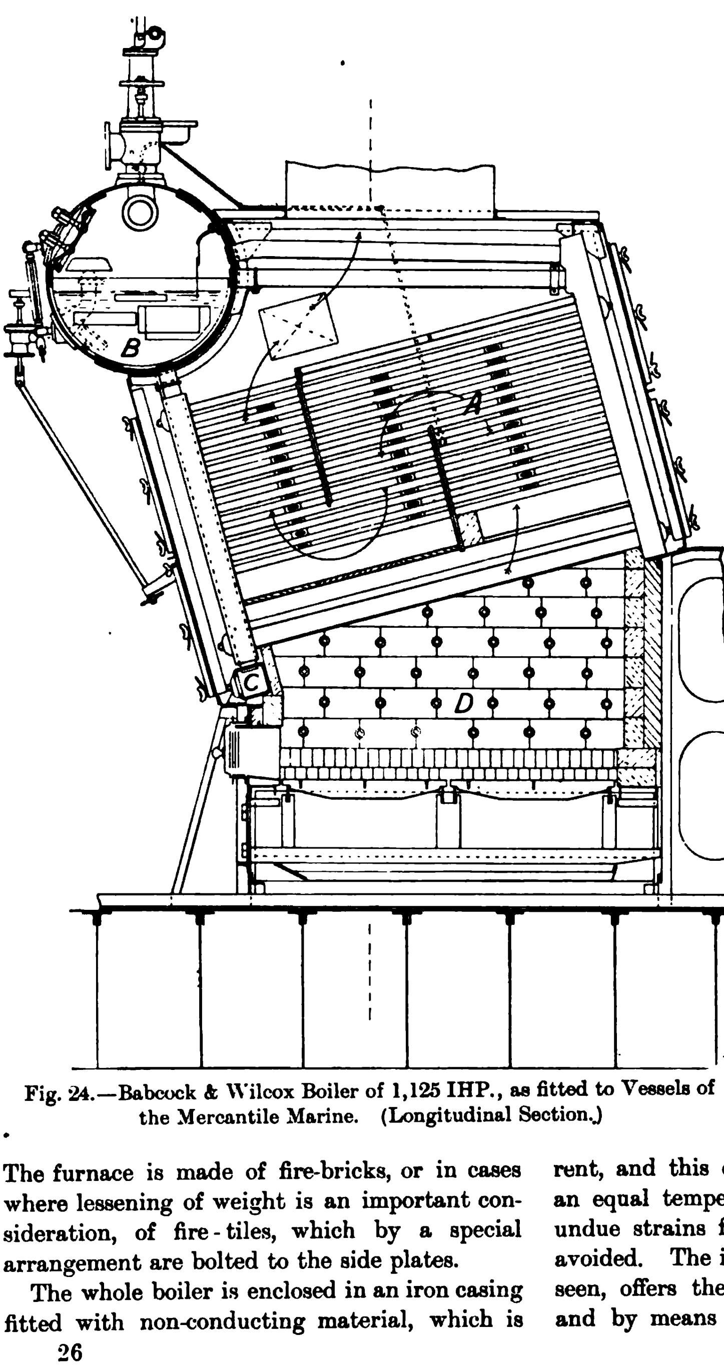


Fig. 24.—Babcock & Wilcox Boiler of 1,125 IHP., as fitted to Vessels of the Mercantile Marine. (Longitudinal Section.)

The furnace is made of fire-bricks, or in cases where lessening of weight is an important consideration, of fire-tiles, which by a special arrangement are bolted to the side plates.

The whole boiler is enclosed in an iron casing fitted with non-conducting material, which is so effective in preventing the radiation of heat that the outside of the casing remains quite cool. The steam and water drum B is of large capacity, and made of steel plate. The sinuous headers of wrought steel, are of such ample strength that even with the highest pressures no stay bolts are required. The same may be said of the mud drum C. The tubes are of seamless steel. Opposite the end of each tube, or each group of tubes, is an internal fitting or door, the joint being made on the inside of the header by means of an asbestos wire woven ring. The door is drawn up into place by an outside bolt, with nut, and cross bar and cap. All the steam mountings, such as stop-valves, water-gauges, safety-valves, &c., are attached to the steam and water drum B. The blow-out valves are fastened to the mud drum C. The steam and water drum B is fitted with wash plates to prevent undue movement of the water when the ship is rolling.

The steam generated in the tubes of the boiler rises vertically through the rear headers into the steam and water drum B, whence the water returns through the short connections between the steam and water drum and the front headers of the tubes. Thus there is a continuous circulation of the water in one direction, not hindered by any counter current, and this continuous circulation produces an equal temperature in all its parts, so that undue strains from unequal temperatures are avoided. The interior of the boiler, as will be seen, offers the greatest facility for cleaning, and by means of doors arranged in the side

castings opportunity is given for the removal of soot.

With regard to the performance of these boilers at sea, commencing with the British Navy, the first vessel fitted was the torpedo gunboat *Sheldrake* in 1898. Trials were carried out both at the Renfrew Works, and in the vessel, when satisfactory results were obtained. The consumption of coal on one occasion was as low as 1·42 lb. per IHP. per hour, and taking a mean of nine separate 1000-mile trials run under varying conditions of weather and sea service, the consumption was 1·62 lb. per IHP. per hour for all purposes. Since these trials the vessel has passed through several commissions; the boilers have been subjected to a number of water, and coal consumption trials by the Boiler Committee, and the ship is at present employed for instructional purposes to drill drafts of engineers, artificers, and stokers, in the working and maintenance of the Babcock & Wilcox Boiler. Since their installation on board, the boilers have proved that economical results may be obtained

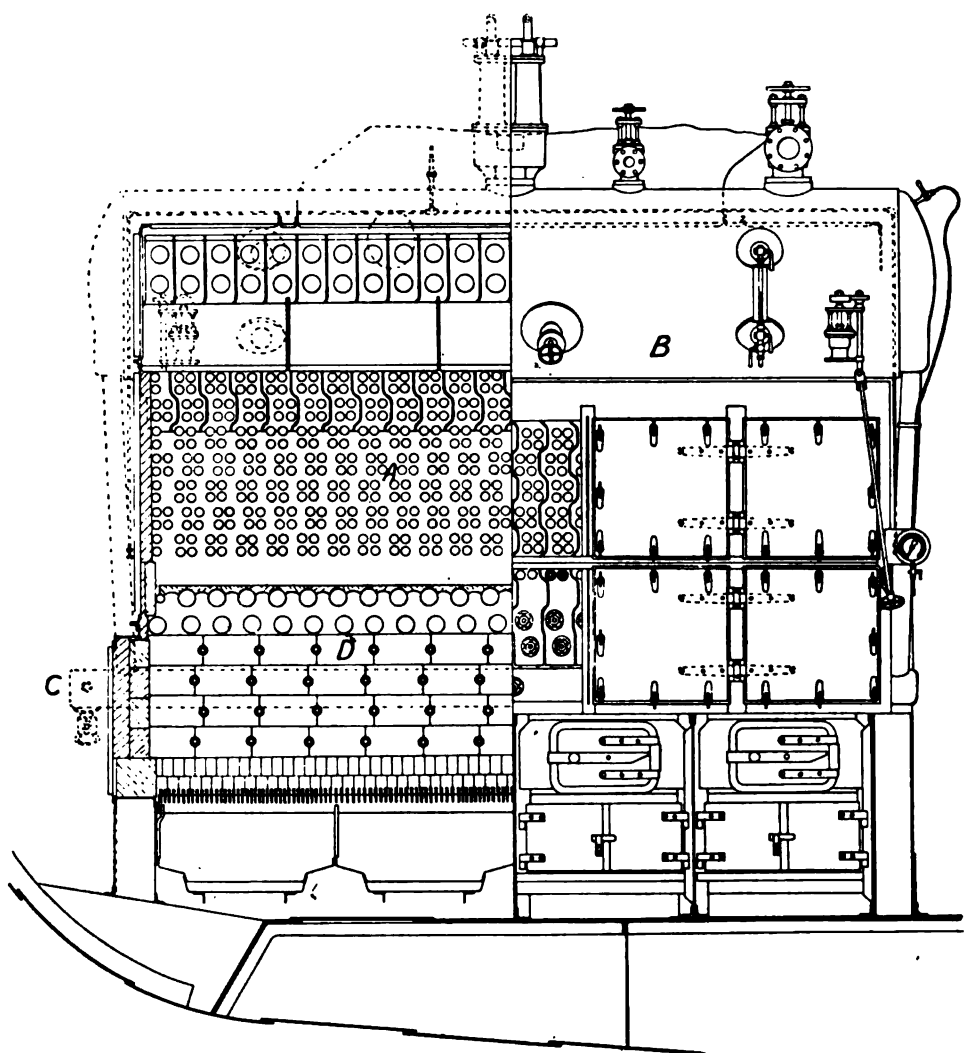


Fig. 25.—Babcock & Wilcox Boiler. (Transverse Section, and Front Elevation of Fig. 24.)

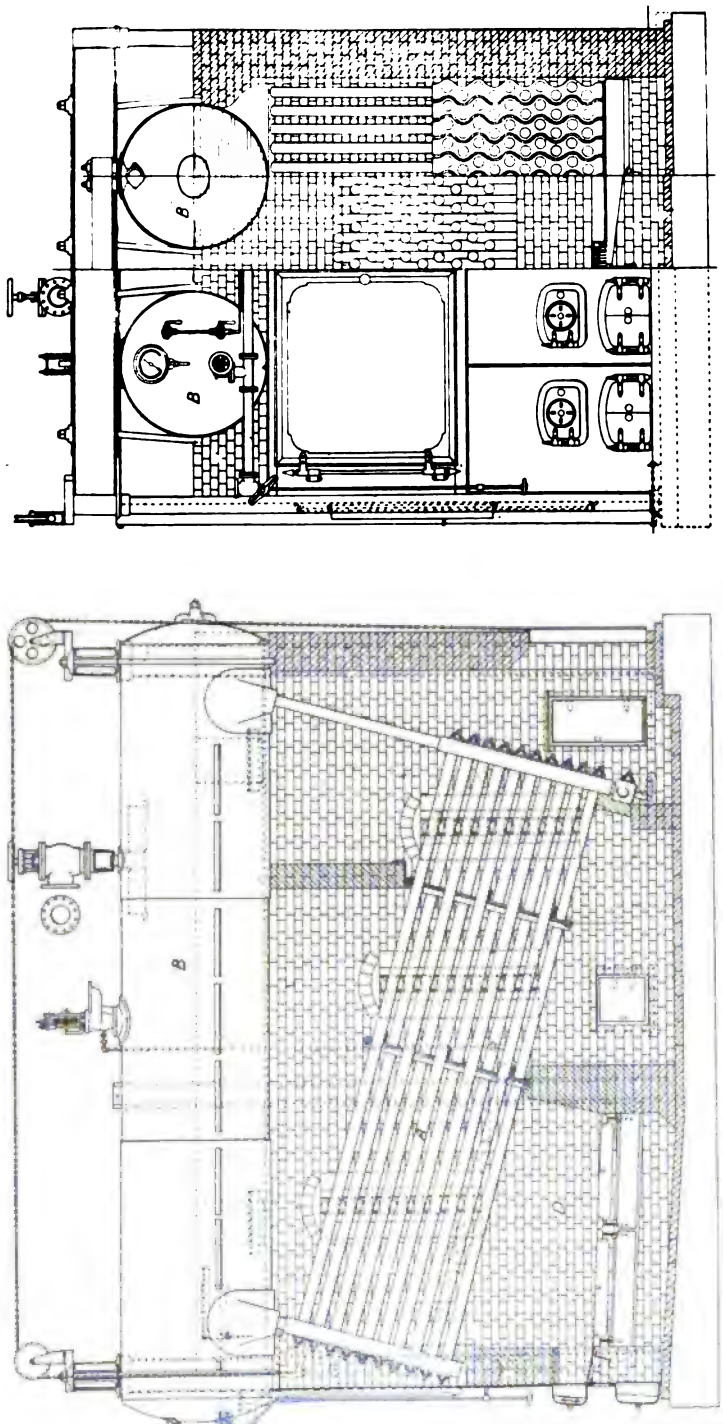


Fig. 26.—Babcock & Wilcox Boiler, Land Type.

with inexperienced firemen and poor coal. This was clearly demonstrated during the manœuvres of 1900, prior to which, fresh hands were put on board, not one of whom had had any previous experience in firing water-tube boilers; yet the *Sheldrake* was able to maintain a higher speed with a lower consumption of coal than any other vessel of her class. This says much for the simplicity of construction of the boilers, and the ease with which they are kept clean inside and out. That the installation of the *Sheldrake's* boilers was satisfactory to the Admiralty officials is shown by the fact that subsequently orders were issued for the fitting of Babcock & Wilcox boilers to the twin screw sloop *Espiegle* of 1,400 IHP., the twin screw sloop *Odin* of 1,400 IHP., the *Challenger*, a cruiser of 12,500 IHP., the *Hermes*, a cruiser of 10,000 IHP., and the *Queen*, a battleship of 15,000 IHP., and more recently to the new battleships *King Edward VII.*, *Dominion*, *Commonwealth*, and *Hindustan*, of 18,000 IHP. each, and the first-class cruiser *Argyll*, of 21,000 IHP. Other ships are the *Black Prince*, of 23,500 IHP., the *Duke of Edinburgh*, of 23,500 IHP., the *Britannia*, of 18,000 IHP., the *Hibernia*, of 18,000 IHP., the *Africa*, of 18,000 IHP., the *Lord Nelson*, of 16,750 IHP., and the *Minotaur*, of 27,000 IHP.

Passing to the American Navy, Admiral Melville's well-known support of the Babcock

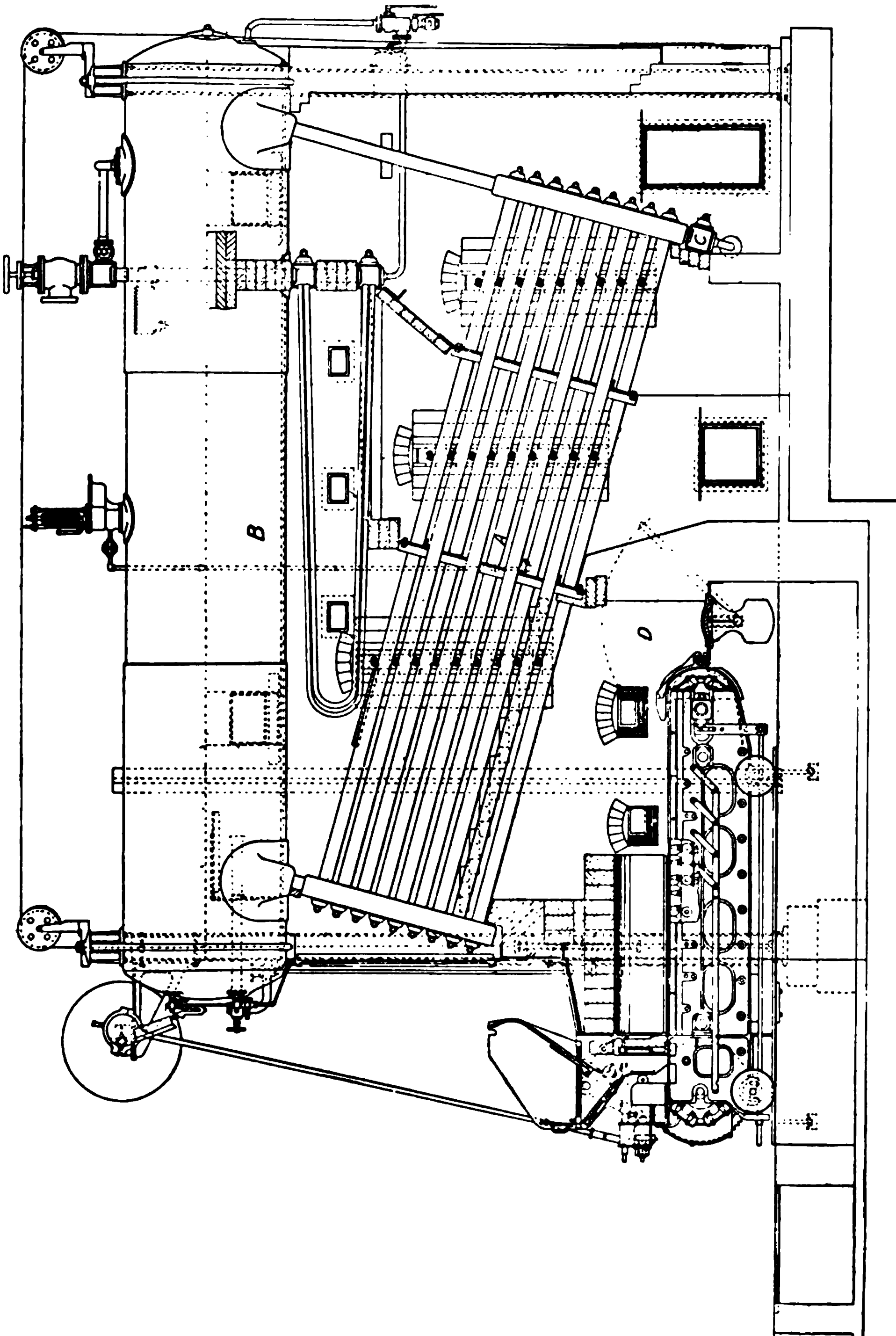


Fig. 27.—Babcock & Wilcox Boiler fitted with Mechanical Stoker. (Longitudinal Section.)

& Wilcox type, and the satisfactory performance of the gunboat *Marietta* during the American-Spanish War, when, with her Babcock & Wilcox boilers, she steamed 12,000 miles without a hitch or stoppage excepting for coal, and proceeded almost immediately afterwards to join the squadron on active service, is an old story. The American Naval Authorities have to a large extent adopted the Babcock & Wilcox type for forty vessels recently built, or building. These boilers have been made for Russian, Italian, Norwegian, Spanish, and Danish warships. In the merchant service boilers have been fitted to vessels on ocean cargo, and passenger service, on lake and river cargo, and passenger service, and on sea-going dredgers, river dredgers, ferry boats, launches, tugs, yachts, and barges.

The illustrations Figs. 27, and 28 (Plate I.) show a mechanical stoker of the chain and grate type fitted to the boiler. The grate consists of an endless chain of stout cast-iron grate bars linked together and traversed by drums at front and rear, the first drum being revolved by a worm and worm wheel. The coal is fed over the whole width of the grate. The depth of the fire is regulated by adjustment of the fire doors, which lift vertically. The speed of travel of the grate is regulated by a ratchet and pawl attachment on the driving worm. The latter engages with a worm wheel, on the shaft of which is one of the drums by which the grate is revolved. The whole grate can be drawn out bodily from the boiler, its framings running on wheels flanking the sides of the ash-pit.

Baby Bessemer Converter.—*See* **Bessemer Converter.**

Back.—This term has numerous meanings, some obvious, others not. Thus the back of a lathe or machine is the rear side, or the opposite from that at which the attendant controls its operations. But it also signifies the top, or the bottom, in some cases, as the back of a moulding box, whether that be in top or bottom. It is also the top of an arch. The back of a forge is the rear, through which the tuyere enters, but the back of a hand rail is the upper surface, and the back of a saw is its upper edge, as is that of a chisel. The back of a slide valve is the face opposite to the sliding or working face. The term is also prefixed to many others; as back guys, the hinder timbers of derrick cranes, the hinder ropes of shear legs, one of the links in a parallel motion, the hinder gears of a lathe, or milling, or drilling machine, though these are often placed below the main spindle. Some of these terms are given below.

Back Centre.—The back centre is employed in turning lathes, and grinding machines to carry the outer end of work supported at the driving head end, and which cannot be carried by the latter alone. It is also employed to a certain extent for supporting the ends of milling cutter arbors, and for the tailstocks of dividing centres, for planers, shapers, and millers.

The common lathe and grinder centre, Fig. 29, A, is made with various angles of point, but the one of 60° shown is coming more and more into general use as a standard. Sometimes for heavy work steeper angles are used, ranging from 70° to 90°, especially in Continental practice, but the 60° angle has been proved capable of carrying the heaviest classes of work, and will doubtless become standard for all centres in time. The convenience of having every centre, and every hole in work uniform is obvious, especially when pieces have to be changed, as from lathe to grinder; and the various centre drills which are manufactured embody the 60° angle.

Special forms of centres, shown in succeeding Figures, differ from A in the style of point. They are used both on lathe, and grinder. B is the cut-away, designed to give clearance, so that either a turning tool, a file, or a grinding wheel may pass along over the end of work of small diameter, which it could not do if a whole centre stood out in the way. This is also a necessary type for milling-centres, allowing cutters to finish to the end of small work, such as when fluting taps, reamers, &c.

Some pieces, as pivots, are not recessed in their ends to receive a point centre, but are pointed, and a hollow centre is then used, C, in which the work runs. A semi-globular recess is also occasionally employed, receiving a ball-shaped end, chiefly of use in taper-boring bars, which have to travel round in a wobbling path.

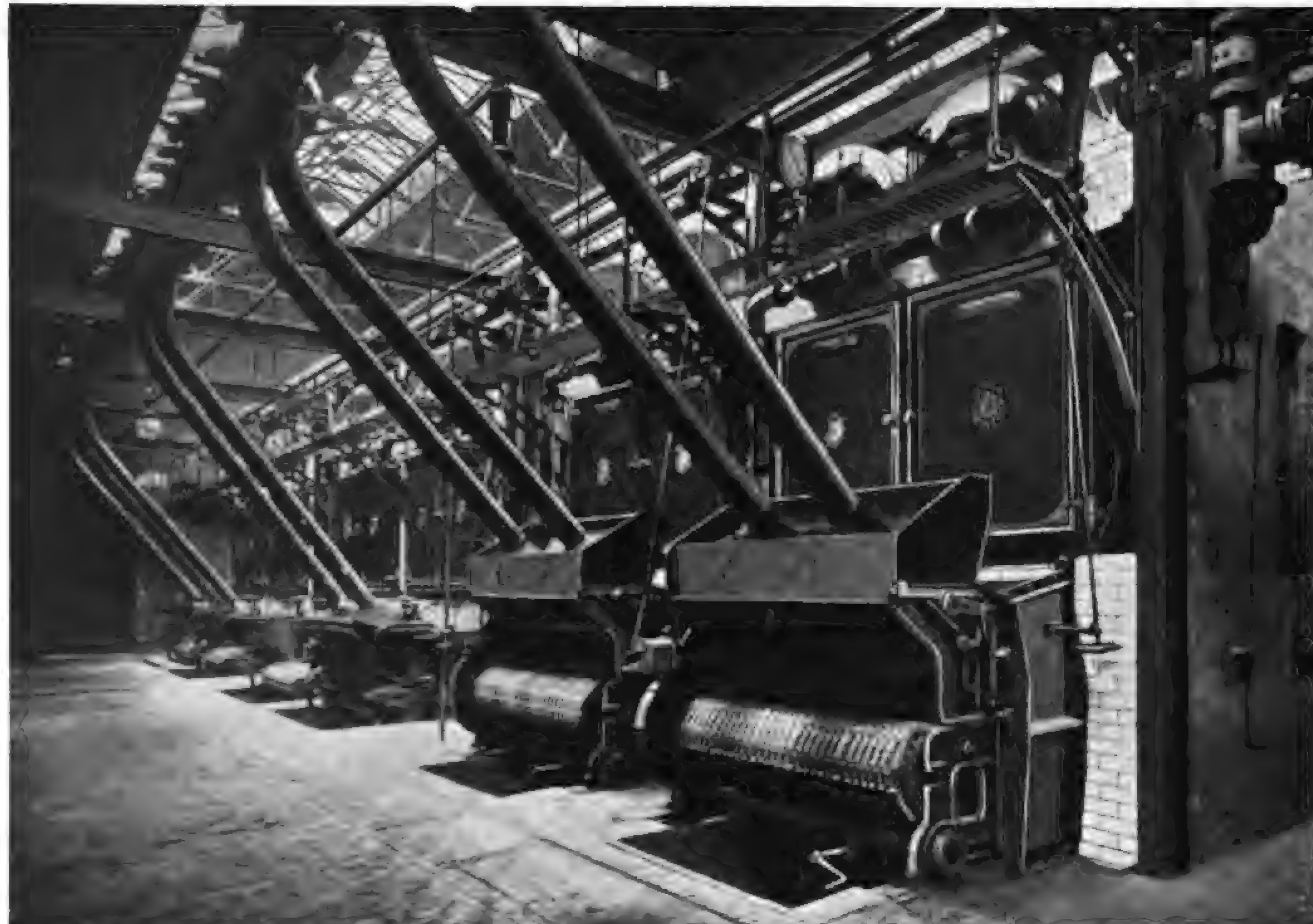


Fig. 28.—Babcock & Wilcox Boilers at Wigan, fitted with Mechanical Stokers.

To face page 30.

When tubes and other hollow objects have to be carried, the centre must be of larger diameter, as at D. In the bigger sizes, the friction of the work is rather excessive, and it rapidly becomes bell mouthed, especially if of soft material. The Taylor ball-thrust centre, E, is designed for preventing this, and allowing of easy running. The taper cone revolves freely with the work,

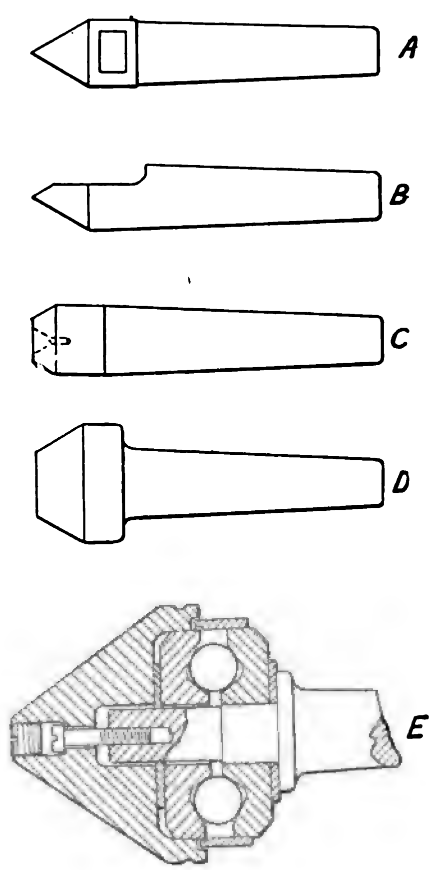


Fig. 29.—Back Centres.

A. Common lathe centre. *B.* Ditto, cut away. *C.* Hollow centre. *D.* Centre for tubes. *E.* Ball-thrust centre.

and the thrust is taken against the ring of balls seen. No wear therefore can occur between the work and the centre. The long central screw shown prevents the cone from falling off when out of use, and the grub screw at the end keeps out dirt or grit. The tapered shank fits in the poppet spindle in a similar manner to the other centres shown above.

The attachment of centres to their spindles or barrels is now universally by tapers, ensuring concentricity and true alignment, which could not be said of the older method of fitting by screw threads. A good many various angles are in use, evolved by different firms, but the use of the **Morse Taper** is extending, and the standardisation which follows is advantageous from the interchangeable point of view. The centres for milling machine footstocks are frequently made as long rectangular strips, flatted along the top, the circular shank being dispensed with.

The removal of centres is effected either by twisting them out with the help of a spanner upon the flats, Fig. 29, A, or by pushing them out with an extension of the poppet screw (for details of which *see* **Poppets**). Another matter which will be found under this head is the spring fitting of centres,—allowing them to give a little endwise, in case of longitudinal expansion of the work due to heating. With a rigid centre the work would warp and curve, and so be finished inaccurately. This is a point of much importance in precision grinding.

Centres must be hardened, to enable them to remain true and to delay wear; re-grinding is necessary at intervals, as scoring appears.

Lubrication is usually effected by simply pouring oil on the centre at intervals,—running it back a little to let the lubricant get down into the centre hole. To render the operation easier, hollow centres are used, having passages to convey the oil to the point, so that it drops right into the little clearance hole at the bottom of the centre recess.

The square centre is a type employed for truing out the holes in work, and getting the latter to run concentrically. *See also* **Centring, Centre Grinder.**

Back Cut-off Valve.—*See* **Cut-off Valve.**

Back Draught.—A term which signifies the rushing back of flame and hot gases from the furnace doors of a steam boiler. Men have been burnt to death from this cause. Two suffered thus in the stokehold of a torpedo boat off Portsmouth. The worst accident of this kind was that which occurred off Margate during the contractor's trial of the *Barracouta* on 7th February 1900, in which two men were burnt to death, and others injured. This

accident, typical of others, appears to have been due to the water getting too low in the port boiler, with the result that the top part of the combustion chamber, and the tube plates for some distance down had become overheated, and the joints in the tube plates leaked. Steam and water at 150 lb. pressure were then discharged into the hot chamber, and on the fire-brick bridges. A pressure was thus created sufficient to overcome the flame coming towards the combustion chamber and to force it backwards through the fire-bars into the stokehold, overcoming the air pressure due to the fans.

Explosions in the flues of Cornish and Lancashire boilers are not of uncommon occurrence. They are generally supposed to be due to accumulations of coal gas in the brick-work flues, and to the intermixture of the gas with atmospheric air in such proportions as to produce explosive mixtures. Fortunately they are seldom very destructive, the general effect often being only to blow open the furnace doors, and drive a jet of flame out of the furnace mouth with a portion of the burning fuel. In more serious cases a portion of the brick-work enclosing the flues has been dislodged. In others the seams of the boiler have been strained. In nearly every case the explosion has happened after the fires have been banked down at the week end, and the dampers nearly or entirely closed, a fact which gives entire countenance to the belief that such explosions are due to accumulations of gas in the flues, consequent on the coking of the coal in the furnaces, and the generation of quantities of gas which have been prevented from getting away by reason of the absence of draught.

The time which has elapsed between the charging of the fires, and the explosions has varied from the act of stoking, to about five minutes, or a couple of hours. The cause is probably due in most cases either to faulty details in the arrangements of flues and dampers, or to bad firing. The passages must be large enough, in order to ensure complete combustion of the gases before they get into the flues. The dampers must be capable of opening fully when required, to prevent accumulation of gas at the tops of the flues. In the firing, the coals should be thrown on the front of the furnace, and not at the back, so that the gases which they give off shall be burnt by the bright fire at the back. Such explosions, too, have been frequent in boilers fired with producer gas.

Back Firing.—Denotes the escape of a portion of the charge of a gas engine at the ports. To prevent this the valve is closed as rapidly as possible after ignition.

Back Gear.—This well-known device affords a very convenient and elastic means whereby the belt power of various machines can be increased by the corresponding sacrifice of speed. It is therefore used on lathes, boring, drilling, milling, and other machines. It is a device which permits of wide variations also, first by the combination of numerous cone speeds therewith, and second by duplicating the back gear spindles and wheels.

The objections to back gear are the necessity of slowing down speed with increase in power, and for this reason it is abandoned in many modern types of high-speed lathes, drilling, and milling machines, in favour of a more powerful belt drive obtained by the employment of broad quick-running belts. This practice has been growing for five or six years past. But the advent of the high speed steels has had the effect of accelerating that development. The electric drive is also tending to lessen the use of back gear, and of cones, since speeds can be changed by electrical devices. But it is hardly to be expected that these changes will have any more effect than to set some limitations to the employment of the device. It seems to be far too valuable to be abandoned, or even to be largely displaced.

The simplest and commonest back gear is that shown in Fig. 30. It involves making the back gear spindle with its two gears, capable of being thrown into or out of engagement with the gears on the main spindle. When "in," the front wheel D, keyed to its spindle, is unlocked from the cones, so that the spindle is driven slowly in the ratios of the gears through A, B, C, D.

If the teeth are respectively as follows:—

A 18, B 54, C 18, D 54.

then the ratios will be

$$\frac{B \times D}{A \times C} = 9,$$

and the spindle will make one revolution to nine of the cones.

When "out," the spindle is driven by the cones, which are locked to it by bolting the

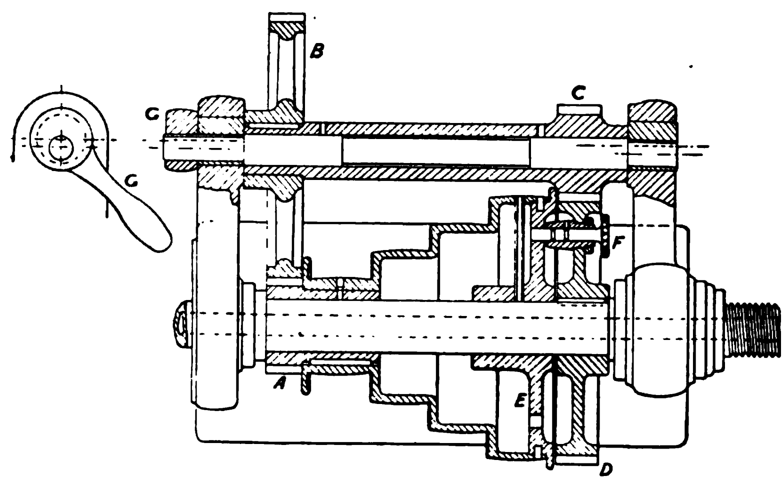


Fig. 30.—Common Back Gear.

wheel D to the cones through the plate E by the spring pin F.

The methods of putting the back gear spindle in or out vary in different lathes. Sometimes the spindle is slid endwise. In most cases it is thrown backwards by an eccentric movement as at G.

In modern lathe making there is a very marked growth in the practice of increasing the range of the back gears, intermediate gears being introduced with a view to give a mean between extremes. In some lathes, twenty-four changes of spindle speed are thus obtainable if two pairs of pulleys are used on the countershaft. Fig. 31 shows the arrangement used. It comprises two extra wheels, one on the mandrel, and one on the hinder sleeve. The wheels A and B correspond with those ordinarily used. C and D are the extra ones producing the intermediate speeds, quicker in action than A and B, and slightly slower than direct running of the belt on the cones. It is advantageous in cases in which a slow belt movement alone would not be sufficient without the back gear, and for which the higher gear would be excessively slow. It will be observed that the width and strength of the gears is increased in proportion to the work they have to do.

The back gear in treble-geared lathes is arranged to produce regular gradations of speed, in a geometric, or approximately geometric, ratio. Thus each increase in power is three times that of the last. As say, 5 to 1, 15 to 1, and 45 to 1; or three and a half times, as 5 to 1, $17\frac{1}{2}$ to 1, and $61\frac{1}{4}$ to 1.

In a treble-geared lathe there are three rates or changes of speed possible, corresponding with single drive, double, and treble gear. These changes are constant, being due to the gears. But the speeds of the headstock spindle are capable of as many rates of speed

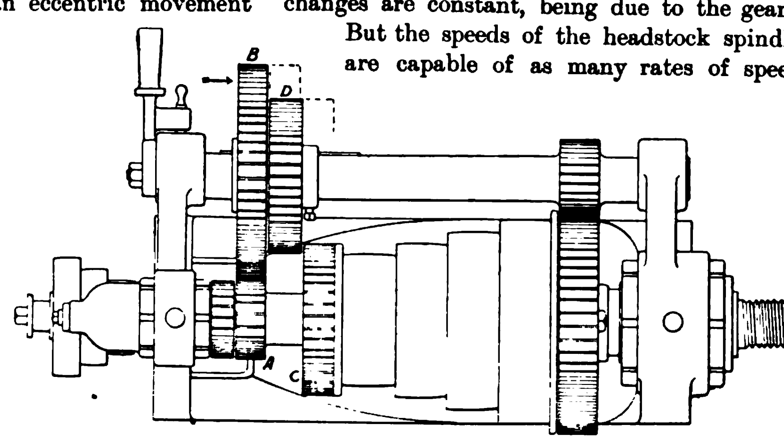


Fig. 31.—Intermediate Back Gear.

within the changes due to gear as there are steps upon the cone pulley. So that if there are five speeds to the cone pulley there are $3 \times 5 = 15$ rates of mandrel speed within the range of the lathe.

Fig. 32 is illustrative of the method of

driving heavy lathes from a cone pulley on a shaft distinct from the main mandrel. The latter A is of steel, or in the heaviest types of lathes, of cast iron. It conforms roughly to the

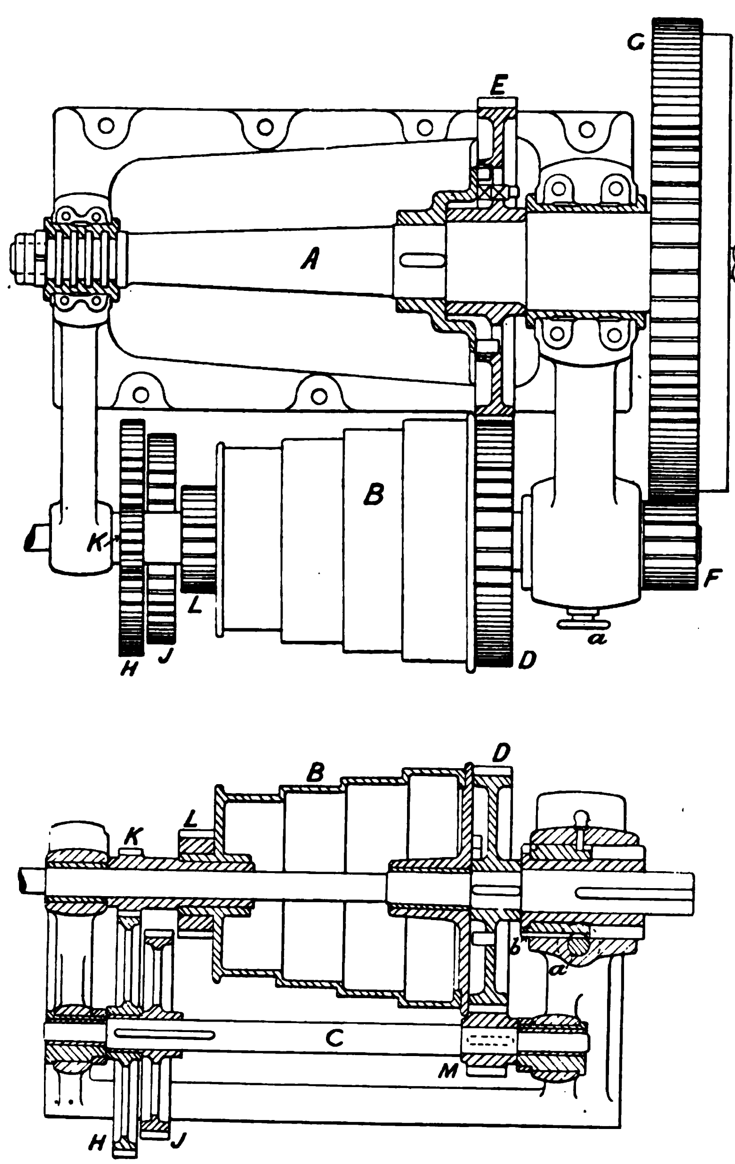


Fig. 32.—Back Gears disconnected from Main Mandrel.

parabolic outline, which is the correct form for a mandrel, and in this instance, and in a goodly number of other examples, the pressure on the tail end is sustained by a thrust type of bearing. The driving is done from the cones B, either directly, or through the back gear shaft C, placed in front of the headstock as is usual with lathes of this class. The difference between this, and the ordinary lathes of this general type consists in the introduction of additional gear on the back shaft C, for the purpose of obtaining a wider gradation of speeds, being similar in degree, though differently arranged, to the smaller screw cutting lathes of Fig. 30.

In Fig. 32 the arrangements are as follows. The cones B being locked to the wheel D, will drive wheel E and the mandrel A at a quick speed for light turning. Unlocking wheel E, a pinion F, in direct gear with the ring of teeth G on the face plate, will drive that at a slow speed. The pinion can be slid back out of gear by means of a hand wheel *a* and rack at *b*. The wheels H and J on the back shaft C gearing with pinions K and L on the cone mandrel, take the place of the one pair of gears usually employed. They slide lengthwise on C to bring one or the other into gear. The driving then takes place from the cones B, through K and H, or L and J to M and D. Thence the driving may be done through E on the main mandrel, or through the pinion F to the edge of the face plate. There will thus be twenty-four changes of speed obtainable; four through the cones to the main mandrel, and four each through the cones to each of the other combinations named.

In some large break lathes the back gear (the incongruity must pass) is brought to the

front of the speed cones. The idea is to bring the gear in line with the locality of greatest stress in cutting. The last spindle which carries the pinion that gears into the ring of teeth on the back of the face plate is thus at the front of the lathe instead of at the back as is the usual practice.

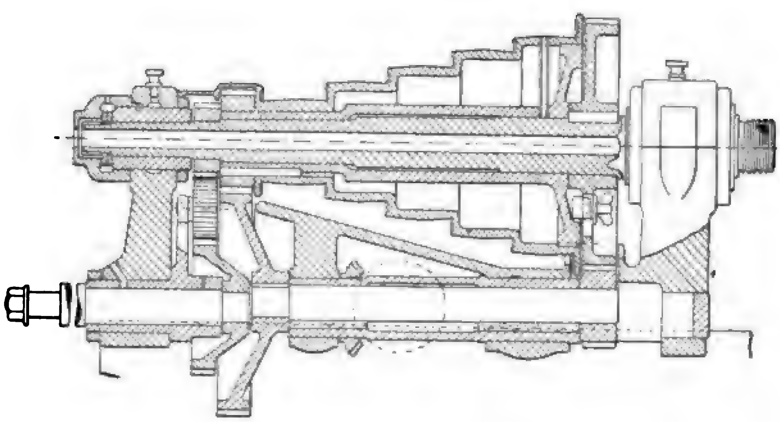


Fig. 33.—Back Gears placed below Main Spindle.

The back gear in many Continental lathes is of the single helical form. It is also of this type in some English break lathes, and wheel and pulley lathes.

There are numerous methods of arranging simple back gears. Generally they are at the back, but a good many examples occur in which they are set below, Fig. 33, both in lathes, and in milling machines. The object in doing so is to keep them out of the way. They are also well protected, and it allows the main gears also to be protected with guards.

The proportions of the teeth of the back gears are generally made alike for both pairs, although the strain on the first set is less than that on the second. In most American lathes the first set is made narrower, and of finer pitch than the second.

The methods of fitting back gears vary. The best job is made when the back gear spindle and its wheel and pinions are cut in solid metal. The alternative is to key the wheels on. The pinion on the main spindle may be cast solidly with the cones, or it may be keyed to an extension boss of the cones. The front spindle wheel keyed to the spindle, is attached or released from the cones by various devices; generally by a sliding bolt, to permit of which, the cones must be fitted with a front plate with grooves for the bolt, and a boss for the spindle.

Generally the teeth of back gear wheels are cut. The older practice was to cast them. But backlash is unavoidable then, which need not occur sensibly in cut teeth.

Back gear spindles—that is, the sleeve portion which carries the gears, are cast vertically, as also are cones. They are turned all over, and the latter must be in perfect balance. The steps of the cones are either turned convex, or with two facets, meeting at the centre.

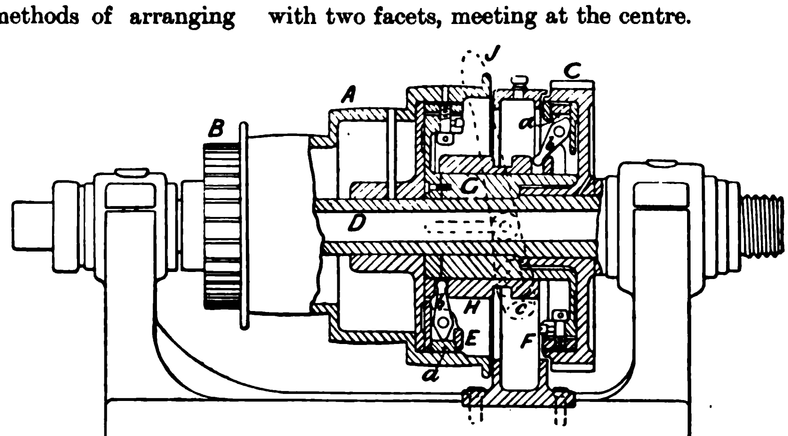


Fig. 34.—Friction Back Gear.

Friction back gear is used on numbers of small lathes to save the time occupied in throwing out the eccentric or other motion. It was first introduced on turret lathes, whence its use has spread to others. There are two or three kinds of mechanism adopted, the split

friction clutch, and the cone type, examples of which are given.

Fig. 34 is a friction operated back gear, the construction of which is as follows. The cones A with the pinion B and the main wheel C run

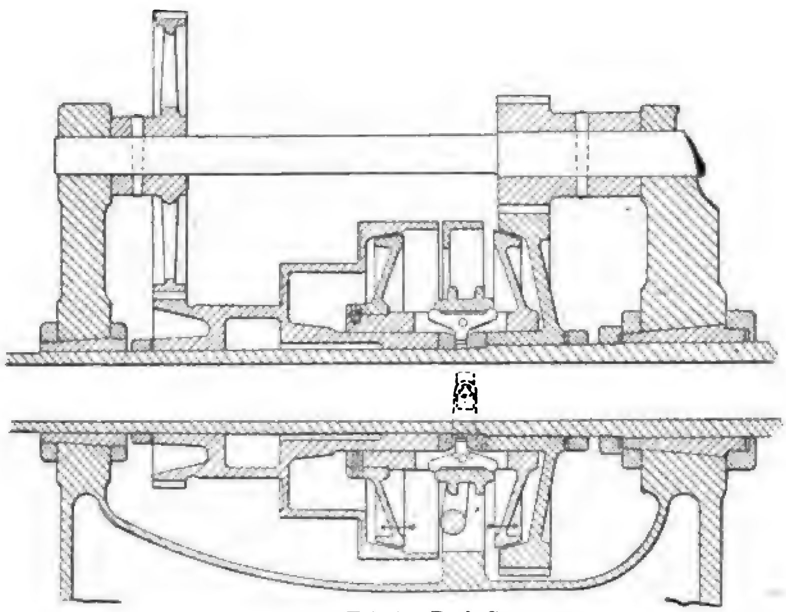


Fig. 35.—Friction Back Gear.

loosely on the mandrel D, and are put into engagement in turn by the expanding friction ring clutches E and F. A boss G encircles the mandrel D, and carries two plates, one cast with it, the other screwed on, and each plate has a return flange which receives the loose split ring clutch that fits within the cones of the wheel. A wedge piece *a a* in each split ring expands it, being thrust outwards by the toggle levers *b b*, operated by a slider H moved along it by the lever J. The lever has its bearings on opposite sides of a casting, and pins slide in the groove, being connected by a fork *c*.

An example of coned clutches is shown in Fig. 35, which but for the coning resembles the previous one. There is a sliding operating sleeve, actuated by a lever, having its bearings in a hooded piece cast in one with the headstock.

Fig. 36 shows a design of friction back gear fitted to the Le Blond milling machines. The wheels A and B run loosely on their shaft, and are put into action through the medium of a hub C, keyed with a Woodruff key to the shaft, and which is surrounded by spring rings D, D. These are forced open by the wedges E, E actuated by the plunger F, connected with the sliding sleeve G, moved by the lever H.

A locking device is fitted to some back gear shafts to prevent risk of the wheels becoming accidentally engaged. One is shown in Fig. 37. The ball handle is held frictionally by the spring plunger, recessed in the headstock casting.

Backing Belt.—In some screw cutting lathes an extra set of pulleys is fitted for the purpose of reversing the direction of rotation

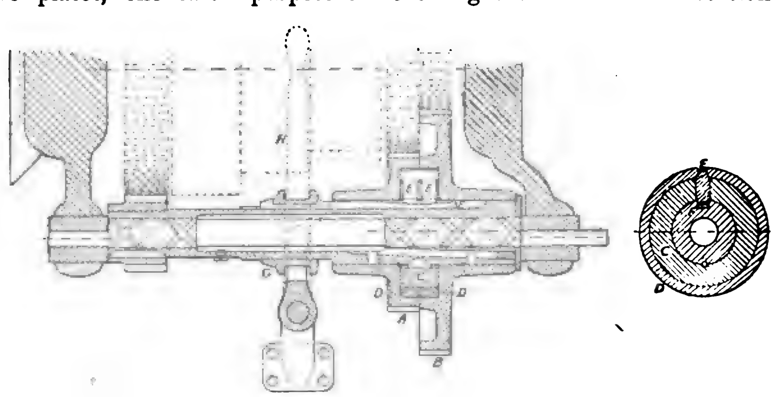


Fig. 36.—Friction Back Gear.

at the termination of the traverse in screw cutting. The advantage lies in the fact that there is then no difficulty in catching the thread for a second or subsequent cuts. The

objection is the time occupied in the return traverse when accomplished in this way, instead of by operating the rack and pinion, unless this is done at a higher speed. But the more serious objection is the extra wear on the lead screw

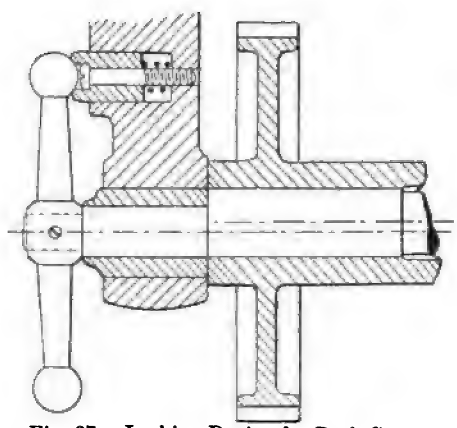


Fig. 37.—Locking Device for Back Gear.

and clasp nut. It is not a usual fitting of lathes, unless ordered. It is fitted to some automatic screw machines for running out taps. The term "reversing top driving apparatus" is sometimes applied to this device.

Backing-off, or Relieving, is the eccentric relief given to the teeth of cutters, extending from the cutting edge back to the end of the tooth. It takes the place of the filed clearance which was formerly put on milling cutters, and provides for the retention of the profile of the cutting edge for a long period, notwithstanding

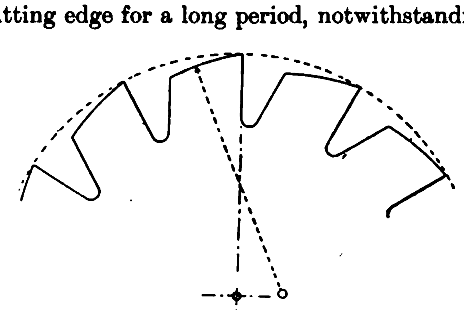


Fig. 38.—Principle of Backing-off.

that a number of grindings or sharpenings have been effected on the cutter. The diagram, Fig. 38, shows how the relief is given, by taking a point away from the central axis of the cutter, and striking a radius from this. Backing-off is then done, using a tool the shape of the cutter edge, which is thus continued uniformly backwards. Grinding of the cutter is done against the radial face, and its only effect is to reduce the diameter of cutter, and thickness of tooth, without changing the outline which it can mill. The old cutters were turned up to shape, and then were sharply relieved or cleared back without retaining the cutting edge profile, so that after getting dull they had to be softened, turned up again, and re-hardened.

The backed-off tooth is a very strong form, and the cutter can be utilised until the teeth become too thin to stand up to their work. The first expense of a relieved cutter is somewhat heavy, when the profile is intricate, but the method nevertheless pays if a large quantity of work has to be milled in duplicate. Reamers and taps are also so relieved, not from any idea of preserving the profile (which is only straight), but to provide a stronger tooth than the flat cleared type.

Backing-off Lathe, or Relieving Lathe.—Lathes that do this work are of a special class which have become developed in consequence of the growth of the milling cutters. They supersede the old methods of filing the clearance of the teeth, and produce the same result with more regularity and rapidity by a to-and-fro movement of the cutting tool.

The relieving lathe shown in Figs. 39-41 by J. E. Reinecker, of Chemnitz Gablenz, is adapted also for general turning and screw cutting. The special mechanism for relieving is actuated from a shaft within the bed, which derives its motion from the change wheels, and differential gears seen at the right-hand end of the bed. We will commence at the headstock end, and trace the mechanism from thence.

The headstock fittings, Fig. 39, resemble in the main those of an ordinary lathe, in the spindle and back gear arrangements. Just beneath the hinder bearing is a stud shaft having a sliding internal key, moved by the knurled knob A, through which the stud shaft can be driven by either of the gears *a* or *b* of equal size, which are mounted on it loosely at its inner end. One engages with a wheel *c*, keyed to the headstock spindle, the other gears with the pinion *d* on the cone pulley. The

cone pulley drive is a device for cutting threads of coarse pitch, and worms; and threads of two different pitches can be cut when the back gear is in, with the same change gears, and in the same ratio as the back gears, which is 16 to 1. The pitch cut when the key A is pushed in is sixteen times as coarse as that when it is out. The shaft B, below, which is an element in the train of mechanism for relieving, is driven from the cone pinion through the pinion *b*, which actuates the train of gears seen beneath, the last of which is *e*, on the end of the shaft B. The gears seen to the left of this are those for reversing the motion of the lead screw.

The shaft B terminates not far from the right-hand end of the bed, being supported there in a bearing seen in section. It carries a mitre wheel *f* at its end, just outside the bearing, which gears with mitres *g* and *h*; and these with *j* are mounted loosely on the short shaft C, its movements being actuated by the worm wheel *k* from the worm *l*. Wheels *g* and *h* turn freely on studs that are fixed opposite each other on an enlarged end of the short shaft C, the whole forming a differential arrangement. The result of keeping the wheel *j* stationary is that the shaft C will be driven at a rate of one-half that of the shaft B. But if *j* is driven by the worm gears *k* and *l*, then the rates of revolution of the two shafts are variously modified by different arrangements of change wheels D set up at the right-hand end of the lathe. To this set another set is geared from the back (compare with the end view in Fig. 39), and thus the relieving shaft F is actuated. Its reversal is effected by gears operated through the lever G, at the left hand of the headstock.

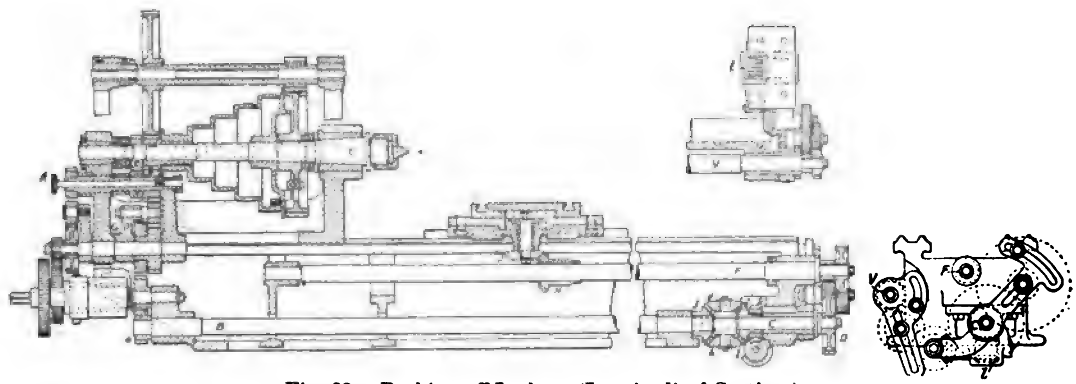


Fig. 39.—Backing-off Lathe. (Longitudinal Section.)

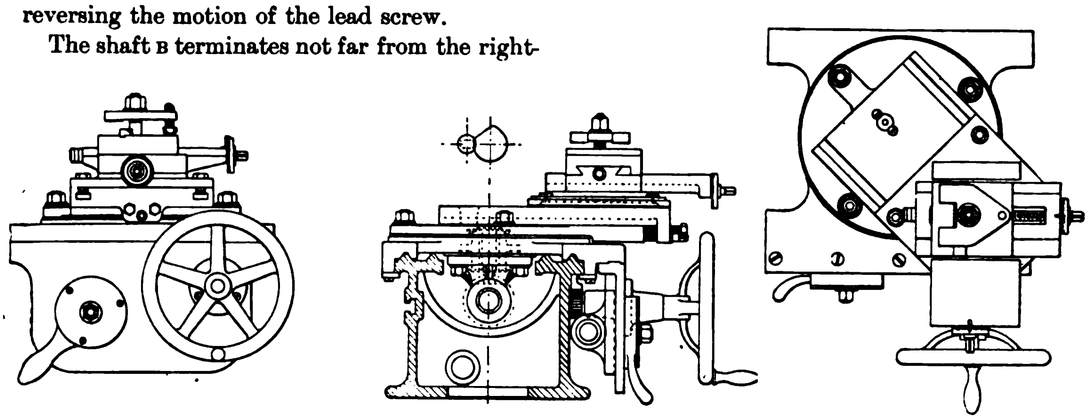


Fig. 40.—Carriage of Backing-off Lathe.

The shaft F is splined to carry a sliding bevel gear H which actuates another J, on a short

vertical shaft passing up through a boss in the slide rest. At the top end of the vertical shaft a cam is fitted, which imparts the necessary to-and-fro movement to the slide, and the relieving tool.

The slide rest is a rather complex apparatus, comprising the carriage, Fig. 40 (compare with Fig. 41, K), to which a plate L is fitted, and secured with bolts, and which forms a bed for the slide M that moves in a transverse direction when relieving. The slide M has a pin at the rear end which is kept in close contact with the edge of the cam by springs at the front end. It, with its tool, is therefore pulled forward by the cam and brought

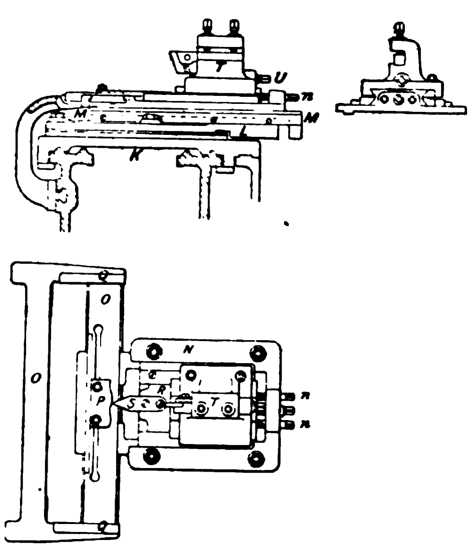


Fig. 41.—Slide of Backing-off Lathe.

back by the springs. The change gears which are at the right-hand end of the bed, time the movement in such a manner that the cam makes as many rotations per single revolution of the tool being operated on as the number of teeth required in the finished cutter.

The plate N fastened to the slide M receives a blade O secured to it, and which carries the former plate P for profiled cutters. Lateral guides Q Q secured to the bed of the lathe coerce the blade O in a transverse direction only. A sliding plate R rests on N, and carries the guide pin S which traverses over the former P. Set screws *n n*, and springs afford the means for adjustment of the plate R. To it the tool holder T is attached, and set by the screw U.

If now, in addition to the transverse motion, the slide rest is traversed longitudinally, the blade O and the former P do not partake of this movement, being prevented by the arms Q Q. The pin S must therefore slide along the former P, and the turning tool in T must partake of the same movement, so producing a cutter of the same profile as P.

If a tool with straight grooves running parallel with the axis is required, the setting up is simple, but if with spiral grooves turning to right or left, the movement of the shaft must either be retarded, or accelerated. A table provided by the firm shows the proper gears to use to give the necessary motion to the mitre gear *j*, to produce either result.

Backlash.—A movement between toothed gears which takes place in a reverse direction to the forward or driving movement. It is due to various causes, such as the acceleration of the rotation of the driven wheel, or the retardation of that of the driver. These may be produced by inequality in the rate of movement of the actuating motor or gears, or in that of the driven mechanism. The effect is that the wheels between which backlash occurs move in a jerky fashion, with some shock, which is injurious to the wheels, and often to the mechanism they operate. The amount of backlash possible corresponds with the flank clearance of the teeth, and therefore, cut gears which have no clearance are unaffected in this manner, which is one point in favour of cutting, over casting. Cast gears, however well made, must have some slight flank clearance; but this may be less in machine-moulded wheels, and in pattern wheels drawn through a stripping plate than with patterns moulded by hand.

Back Plate.—The plate which is bolted to the back of a moulding box when deep work has to be poured vertically in a pit. The object of this plate is to prevent risk of the liquid pressure due to the head of metal from forcing the sand of the mould out between the bars of the box.

Back plates are made of from 1 in. to 2 in. in thickness, increasing with area. To permit of

their being bolted to the backs or outsides of the boxes, flanges are cast on boxes which are designed for vertical casting. They are generally made in open sand. They may have holes cast in them to form openings for vents from the mould, or the latter can be taken out at the joints.

Back Pressure.—Signifies the pressure exercised by steam during the period of its escape from an engine cylinder. It is two or three pounds higher than the atmospheric pressure; or the vacuum, in non-condensing, and condensing engines respectively. The slight excess is due to the friction of the steam in the passages, which is an argument in favour of short direct passages.

Back Pressure Valve.—Any valve which prevents the return of fluid or liquid which has passed through it, due to a change in pressure. The valve therefore opens or lifts in one direction only, that of the normal flow. The terms check, non-return, foot valve are applied to specific groups, under which examples will be given. They are made in all sizes, and designs for many classes of prime movers, and their connections.

Back Rest.—*See* **Back Steady Rest.**

Back Saw.—Saws that are stiffened by a thick strip of metal fitted over their backs are known as back saws, though they more often go by names which indicate the special purposes they are intended for, such as—tenon saw, dovetail saw, &c. The purpose of the back is to stiffen and prevent the saw blade from bending. This makes it possible to have the blade much thinner than would otherwise be advisable. Backs are made of iron in the cheaper saws, of brass in the better qualities. Brass is heavier than iron, and weight keeps the saw to its work.

Back Shaft.—The hinder shaft of a lathe, which transmits motion from the headstock to the slide rest for traversing and surfacing, but not for screw cutting, which is the function of the leading or guide screw.

The arrangements of back shafts vary. They are either belt or gear driven, the former being common in the larger lathes of older design. Provision is embodied at the headstock end for reversing the direction of rotation of the shaft for up and down traverse. The cross traverse movement is put in from the front of the carriage, usually by cone friction.

In many lathes the shaft is moved from its position at the back to the front, below the lead screw. It is then termed the feed shaft, or feed rod. This position gives some advantages over the other, which will be considered under **Feed Shafts**.

Back Steady Rest, or **Back Rest**, or **Back Stay.**—This appliance is employed both on lathes and grinding machines, which are used for turning and grinding cylindrical work. It is necessary on account of the insufficient rigidity of pieces in which the length is many times greater than the diameter. If such work —a shaft for example—is placed between centres, and a cut taken along, the necessity for back support is found directly the tool, or grinding wheel gets away from the vicinity of the ends. The natural and unavoidable flexibility of the shaft lets it spring away from the cutting pressure, instead of standing up rigidly, as a short stiff piece would do. Several evil effects follow from this:—A turning cut cannot be taken, because the shaft commences to bend and climb up over the tool point, ultimately breaking the latter, or jumping out of the lathe. If a light cut only is being made, the shaft will vibrate excessively, leaving chatter marks all around, and the results cannot be accurate. This is especially the case if the material being turned is of uneven texture, having hard and soft spots at various locations.

The effect of spring is very marked in grinding with revolving wheels. Lack of back support is at once apparent in the wavy chatter marks upon the surfaces, and the want of circular and longitudinal accuracy.

There are two principal types of back rests—the fixed, and the travelling; the former are employed when only a certain spot upon the work is available for receiving the rest, which occurs in rough work, and shouldered shafts; the latter when the work has already been roughed out to run truly, and the rest can run along it, opposite the tool, so affording support just where required. This type is often termed a follow rest. The fixed rests are attached to any convenient location of the lathe or grinder

bed, the travelling ones are fastened to the slide rest, or to the wheel slide. The actual portion or shoe which supports the work may be of hard wood, brass, bronze, or hardened steel, and it may take the thrust at back, and top or bottom only, or completely around. As the last named type however does not leave the work free to the action of the tool, it must either be fixed, or must follow the tool, whichever method is more convenient for a particular job.

The Vee steady is one of the commonest types, both for lathes and for grinders, and it

type, B, which is also adjustable to suit diameters. The mode of attachment to the bracket casting provides for up and down and cross motions, with a bolt sliding in the slots shown. An alternative design is that of fitting two plungers in a casting, C, adjusting them with screws, and clamping them with other set screws laterally. The illustration also indicates the method of attaching the steady bracket to the back of the lathe cross slide, and the attitude of the slide rest when turning. The lathe saddle therefore carries both rest and steady along simultaneously.

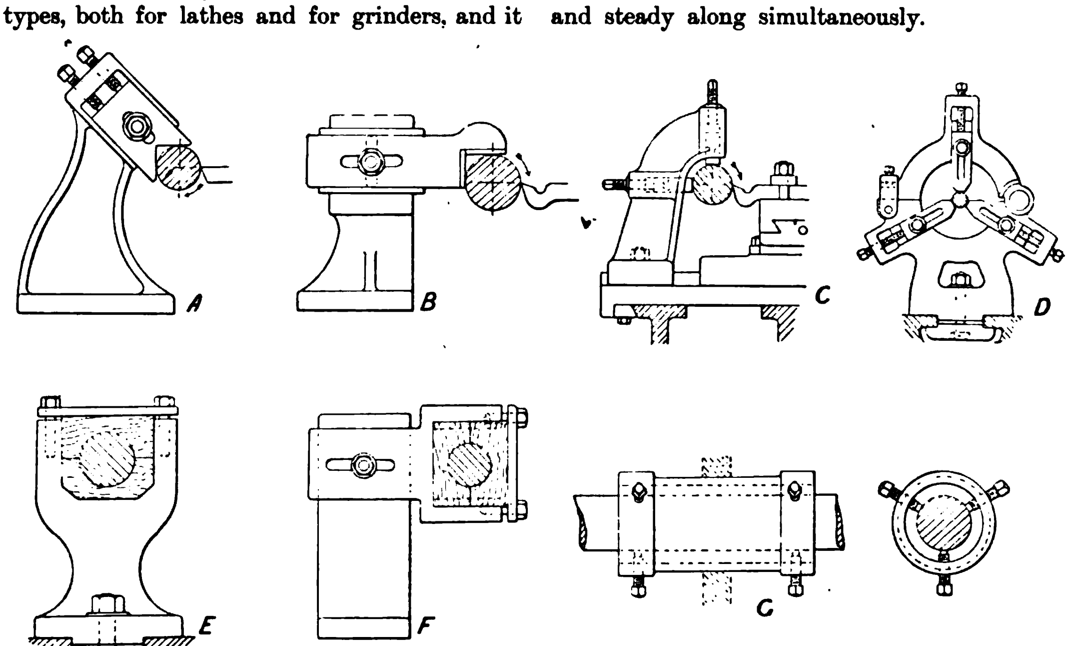


Fig. 42.—Back Steady Rests.

A, B. **Vee steadies.** *C.* **Right-angled steady, Plunger type.** *D.* **Hinged steady.** *E, F.* **Wood steadies.** *G.* **Cat-head.**

effectually prevents the work from springing backwards or upwards. The Vee piece is held in a slide, Fig. 42, A, provided with setting-up screws to accommodate different diameters. The locking bolt clamps the Vee piece rigidly when set for diameter. It may be noted here that the design is used extensively for the special turning tools employed in turret lathes and automatic screw machines, in which provision for cutting to definite diameters is embodied. Reference to these will be found under **Box Tools**.

A form allied to the Vee is the right-angled

Although the succeeding three figures are not back rests alone, since they support the work all around, it is better to include them in this article. The very common form at D, which is shown clamped to the lathe bed, comprises three adjustable strips, which may be firmly gripped after setting to the work. The upper portion is hinged, and fastened with a strap fitting, so that it may be quickly thrown open for the insertion or removal of work. Frequently three screws alone are fitted (instead of the strips), their ends bearing upon the work.

An old form of steady is that in which wood provides the supporting medium, and this design is still in extensive use. Its usual outline is that at E, and at F, which are fixed, and travelling types respectively. The blocks of wood are hollowed out and clamped with a cap on the steady. Occasionally Vee-shaped grooves are made instead of semicircular, to accommodate varying sizes of shafts. The disadvantage of these wooden forms is that they do not permit of ready adjustment, without cutting, as do the other adjustable types illustrated.

When a rough piece of shaft is put in the lathe, there is no portion of it available for the steady to take a bearing upon. This does not matter, provided some part of the shaft runs truly, so that the steady may be put on and a preliminary cut taken. But if no section is true, then the appliance called a cat-head is employed, G, consisting of a collar or thimble, which is pinched upon the rough shaft with the set screws, being adjusted until the outer turned diameter runs truly. A steady rest of any convenient form then embraces the middle, as indicated by the dotted lines, and so supports the shaft while a place is turned for the steady to rest while the shaft is being done. The cat-head may remain during the completion of the turning, if the portion it occupies is to be left unturned. But if finishing has to be done all along, the cat-head must be removed to enable this to be accomplished.

The conditions involved in grinding are not always similar to those in turning, and the back rests are not necessarily used in the same manner. Thus, the rotation of the grinding wheel in Fig. 43, A, tends to force the work downwards, and the rest is accordingly made to resist this, being placed in the opposite way to a lathe steady, in which it is the upward pressure that has to be opposed.

The effects of vibration of a slender shaft are more perceptible in grinding than in turning, because the rapidly revolving wheel induces chattering, which is very marked. Although but a small amount of material may have to be ground off a piece, a steady is employed, which may not perhaps properly embrace the work, but simply touch it, as at A. The shoe may be of wood or of bronze. Where heavy cuts have to be taken a good portion of the circumference of the work is supported by the shoe, which may be hollowed to suit, as at B. This is held in a rest similarly to A.

A number of steadies are required to properly support and prevent vibration in any piece of more than moderate length. A good rule is to provide one rest for each six to ten diameters

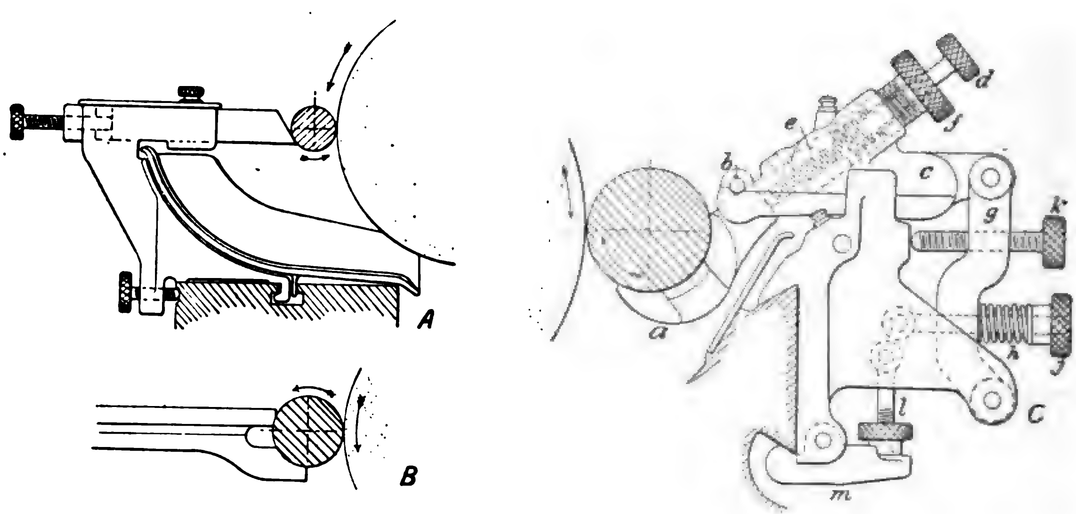


Fig. 43.—Back Steady Rests.

A. **Steady affording simple contact.** *B.* **Steady embracing a position of the circumference.**
C. **Steady capable of minute adjustments.**

in length. The closer the accuracy required in the product the greater is the care which must be observed in setting the steadies. It is obvious that a little extra pressure upon the adjusting screws will bend slender work, and so cause the wheel to cut slightly deeper into the surface than it should do, producing inaccurate results. This fact, however, is sometimes taken advantage of to reduce a diameter minutely at one location, the shoe being pressed in by a faint amount more than normal. The sparks from the wheel indicate the fact that grinding occurs.

In all the rests which we have noticed, the pressure is received against a rigid backing, which does not yield. But for some classes of grinding, springs are introduced behind the shoes to allow the latter to give a little. This device is of utility in the rapid reduction of rough-turned pieces which may not be quite true to size. The spring fitting enables the shoe to accommodate itself to varying diameters, the pressure being slight, but enough to keep the shoe up to the work sufficiently to absorb vibrations. Duplicate pieces are thus finished to size, and the shoes automatically accommodate themselves to the work from the rough to the finished state. The spring is sometimes fitted to the class of steady shown at A and B, pressing in a horizontal direction against the end of the shoe.

A more elaborate style of steady in which this principle is embodied is shown in C, used on the Brown & Sharpe plain, and universal grinders. The shoe *a* is pivoted with trunnions *b*, reposing in a slide *c*. A screw *d* presses on the end of *a* through the medium of the threaded nut *e* and the spiral spring above it. The tension of the latter is adjusted by the hollow screw *f*.

The slide *c* is also spring-fitted; a rocking lever *g* is pushed over by the spring *h*, adjustable by the nut *j*. The screw *k* prevents the slide from exceeding a certain limit of travel. The screw *l* and pivoted clamp *m* are for clamping the entire steady upon the grinding machine slide, shown sectioned.

When in use, the screws are so adjusted that the pressure of the work diameter on the two bearing portions of the shoe *a* compresses the two springs mentioned. As the diameter is ground down, the springs cause the shoe *a* to follow it, until the predetermined limit is reached, and the nut *e*, and the screw *k* fetch up against their respective beddings. This stage is reached each time a piece is ground to size. The spring pressure is only just sufficient to resist the wheel pressure and prevent vibration. The presence of keyways in shafts does not interfere with the revolution in steadies of the type last described, where a good bearing surface is afforded.

The three rests shown in Fig. 43 are designed specially for grinding, but the types A, B, C, and D in Fig. 42 are also extensively used for this work, except that in the cases of A, B, and C they must be placed downwards, to bear up under the work, instead of above, as shown for turning.

Back rests must be well lubricated to ensure the work running smoothly and without heating. Wooden shoes are advantageous from this point of view, because they retain the oil. But this is of little importance when a liberal supply of lubricant is pumped on to the cutting tool, or grinding wheel, in which case the steady is well flooded also.

Back steady rests are also employed in milling, when working on long pieces, which are being splined, or have spirals or screw threads cut upon them. Without some support the work would spring away under the cutter. If the piece does not revolve, a simple packing block, or little screw-elevated support is used, but if rotation occurs, as in screw-milling, a half-round bearing is provided. *See also* **Boring Rest, Cone-Plate,** and **Crank Shaft Steady.**

Backward Gear.— Denotes the arrangement of valve gears, eccentrics, &c., in which an engine runs backwards.

Bacteria Beds.—We are only now learning to dispose satisfactorily of sewage. Early man solved the question by removing himself from the accumulated excreta, a solution that soon became impracticable; the Israelites removed and burnt such matter outside the camp, or covered it with earth; in later times deep trenches were dug and covered with earth when filled; in our days we have cesspools, and earth-closets, sewers which discharge the crude matter

into the sea or water-courses; sewage farms where the sewage is discharged on to the land after the coarser portions have been separated; intermittent downward filtration through a deep porous soil with under-drainage for the purified liquid; precipitation of the solids by means of chemical agents (lime, alum, and iron salts), the precipitate "sludge" being destroyed or sold in cakes as manure; finally the closing years of the nineteenth century witnessed experiments in the treatment of sewage by a process which is swiftly and effectively superseding all the methods of previous centuries, namely, the scientific cultivation of the bacteria present in the sewage.

From 3,000,000 to 7,000,000 organisms have been found in a cubic centimetre of crude sewage, many of them having been isolated and their functions observed. These bacteria are grouped in two main divisions, those which thrive and are vigorously active in the presence of oxygen, and those which do not require oxygen and are checked or even killed by its presence; the former organisms are called "ærobes," the latter "anærobes." These bacteria properly cultivated and not overworked are able to carry out naturally the perfect purification of sewage. As far back as 1865 this was suspected by Dr Mueller who thought that the decomposition of sewage was "chiefly a process of digestion in which the various, mostly microscopically small, animal and vegetable organisms utilise the organically fixed power for their life purposes." This fact was decisively proved by a series of interesting experiments performed at the Paris Sewage Farm by Messrs Schloesing and Muntz. Having discovered the organism which converted nitrogenous matter into nitric acid, they chloroformed the soil in which it was present. Sewage then passed through this soil without undergoing any purification, but directly the organism woke up and again became active the purifying action commenced.

The next landmark in the history of bacterial purification was 1887 when the historic experiments of the State Board of Health of Massachusetts were carried out. The processes of chemical precipitation which were practised in Europe were tried and found wanting. Sixteen beds of sand, each of about one acre in area, were then laid out and fed with sewage by pipes extending across the surface of the sand, while 6 feet below the surface, drain pipes carried off the effluent. To allow the bacteria a needful period of rest and to ærate the sand-bed the sewage was flowed on to the sand during only six hours in each twenty-four. The experiments were regarded as successful, the filtered liquid being as pure and clear as spring water when 30,000 gallons of sewage per acre per day were dealt with, while 60,000 to 100,000 gallons could be treated without fear of any putrefaction in the effluent. The Massachusetts experiments thus confirmed the theory of bacterial purification, but it was evident that the composition and size of the bacteria beds would necessarily have to vary with local conditions. In England, for example, we do not possess such extensive areas of sand, nor is the sewage so dilute as in America.

At Barking, where London sewage is discharged into the Thames, experiments were carried out by Mr Dibdin in 1891. Sand, pea ballast, burnt ballast, and coke breeze were all tried, the last named proving most effective. The bed was worked for eight hours and then rested for sixteen hours, 411,000 gallons per acre being thus treated in twenty-four hours. The results of the Barking experiments were regarded as successful, although it must be remembered that London sewage is previously chemically treated with lime and copperas, and as Mr Dibdin pointed out, one of the objects of using so much lime was to destroy the bacteria which produce putrefaction, but as "the very essence of sewage purification is the ultimate destruction or resolution into other combinations of the undesirable matters it is evident that an antiseptic process is the very reverse of the object to be aimed at."

But in 1895 the use of chemicals was abandoned, and the first bacteria beds constructed on strictly biological principles were laid down at Sutton in Surrey. At first the crude sewage was screened by a large revolving drum rotated by a paddle wheel which was actuated by the flowing sewage, but that was abandoned in favour of what is known as a septic tank (see next page). This screen held back pieces of paper, vegetable matter, and solid fæces, which were

treated separately. The screened sewage next flowed on to filters of burnt ballast; the effluent from these filters passed into secondary beds of fine coke breeze, issuing thence as a clear and odourless liquid which is used to irrigate land on which peppermint is grown. As in every previous case, immediately the beds were overworked the bacteria slackened or ceased action, and the effluent contained organic matter which underwent subsequent putrefaction. With the success of the Sutton system other towns quickly started similar installations, Oswestry and Leeds leading the van in 1898. In each of these cases however the crude sewage was first robbed of the coarser solid parts by screening, or by subsidence in a large settling tank.

It is now generally recognised that the preliminary chemical precipitation as at Barking, and the screening of the solid matter as at Sutton, were mistakes involving unnecessary expense and trouble, for bacterial action commences while sewage is in its freshest and crudest state. Dr Rideal considers that when fæcal matters are first discharged the earliest changes are ærobic owing to the amount of free oxygen in the water or air. With the exhaustion of this oxygen the ærobic bacteria stand aside so to speak and the anærobes commence their action of disintegrating and liquefying solid particles and reducing nitrogenous organic matter to ammonia. This is the change that occurs in the cesspool and in long and intricate sewers. To ensure complete purification therefore the crude sewage should pass through the anærobic stage and this is ensured in most modern systems by the septic tank. This was first introduced by Mr Cameron at Exeter in 1895. Except for passing through a grit chamber in which sand, gravel, and road detritus sink to the bottom for subsequent removal, the raw sewage goes directly into huge septic tanks of varying capacity—the first at Exeter held 53,800 gallons. These tanks (called also scum tanks) are sometimes open, sometimes closed in. Anærobic conditions are however obtained by the formation on the surface of a thick scum. In the majority of systems the flow through the tank is continuous, but in the "Ames" tank the entire contents are removed at intervals. After a brief stay in the septic tank solid matter becomes liquefied and nitrogenous matter broken up into nitrogen, ammonia, &c. This completes the first stage of bacterial purification, the anærobes have finished their work, and the liquid is now ready for the action of the ærobes in the bacteria beds. The sewage is then oxidised by passing it out of the septic tank through slotted scum plates over a weir to the bacteria beds.

As it is now the turn of the ærobic bacteria to commence action and an abundance of oxygen is necessary, the beds are composed of some porous material. Sand was found successful in America but as our sewage is less dilute than that in the States, beds of this material are liable to become clogged. Coke breeze has generally proved the best substance, but owing either to expense or to the abundance of other suitable material in the locality, bacteria beds have been composed of burnt ballast, clinker, gravel, coal, fine broken limestone, stones, cinders, slag and polarite. These have all been found to work successfully, coke and ballast beds having been in continual use in many places for eight or nine years without renewal. To obtain a chemically pure effluent the sewage is generally passed through a series of beds (arranged where possible in terraces), primary, secondary, and sometimes tertiary, the filtering material in each bed being finer than in the preceding one—the aim being to obtain a more complete aeration and nitrification than in the previous bed. The distribution of the tank effluent over the filter beds was effected in the earlier installations by wooden troughs extending across the bed and provided with numerous side branches all perforated with holes, which however frequently got clogged up. Sudden flushing from the centre or sides of the beds likewise proved unsatisfactory as it produced deep channels and uneven spreading. In some installations the sewage is spread over the beds by perforated pipes laid along their surface. The difficulty has however been best solved by the use of some of the patent distributors mentioned below. Drain-pipes 3 ft., 4 ft., or more under the bed, carry away the effluent. As regards the depth of the filter beds, this varied between 3 ft. and 13 ft. in the Barking experiments and it was found that greater depth produced

little or no effect on the degree of purification. In modern beds the depth varies between 18 in. and 4½ ft., 3 ft. being however the usual depth. The area of the beds naturally varies with local demands but allowance has always to be made for resting empty periods, during which the bacteria recuperate, as it were, from their labours, and the bed again becomes aerated.

In order to increase the working capacity of bacteria beds by stimulating the organisms, experiments have been made in which air was forced through the filter beds. This process, however sound in theory, has failed in practice, being far less effective than the periodic emptying and aerating of the bed. The temperature of the beds has also been artificially raised in order to produce quicker bacterial action and also to prevent freezing in the winter. Whittaker & Bryant's thermal ærobic filter effects this by forcing steam jets into the delivery pipe of a revolving sprinkler.

The biologist and the chemist having shown the practicability of the wholesale purification of sewage by bacterial action, the engineer was not slow to devise apparatus and appliances for the efficient carrying out of these processes which involve a minimum of manual labour, or supervision. The new method of disposal of sewage has in fact given rise to a new and rapidly developing offshoot of engineering practice. The great feature of these appliances is that they are entirely automatic. It is impossible here, however, to give more than a brief glance at these appliances. In any sewerage system the sudden flooding of the sewers by storm water has to be considered and the great disturbance this would occasion in bacteria beds is obvious. Adams-Hydraulics Ltd. make a storm-water diverter which passes a normal supply, but automatically closes against an excess volume. The whole volume is then diverted and discharged through the storm outlet to the river or to special storm-water filters. (The regulations of the Local Government Board as to storm water require that provision shall be made for dealing with a volume of mixed sewage and storm water equal to three times the daily dry weather flow of sewage.)

That the beds should be fed with regularity and with definite quantities is clearly necessary if their working is to be effective. To ensure this a good deal of automatic apparatus is on the market. In Messrs Mather & Platt's mechanical distributor a distributing tank is provided, along one side of which a series of valves is placed, each one opening into a separate bacteria bed. A shaft, on which are fixed cams, one corresponding to each valve, is placed above the row of valves. Each cam is set a little in advance of the next so that when the shaft is rotated the valves will be opened one after the other, this rotation being ensured by the action of the flowing sewage in a neighbouring float chamber connected with the tank by a retaining valve. The rising of the sewage lifts the float, which is connected by levers and pawls to the shaft; the pawl engages in one of the teeth of a ratchet wheel and the shaft rotates. The Adam's air-lock feed is another device for distributing the sewage on to the beds. Here the sewage passes freely through a channel in the apparatus to the beds, and as the bed fills the level rises beneath an air dome; the continued rise of sewage compresses the air, which is then forced through a pipe to the interior of the feed so creating an air lock and blocking the passage of further sewage. Another appliance also acting on the principle of the syphon is employed for automatically discharging the beds. By the use of these devices it is now possible for private houses, colleges, hospitals, &c., to carry out their own sewage purification within an area of a few square yards. A scum tank with small primary and secondary beds at different levels fitted with such automatic feeds and discharges may be left entirely alone once the apparatus is regulated.

To obviate the necessity of laying down secondary and tertiary beds the same firm has a system of multiple contact beds. In this the contact bed is subdivided, the different sections being connected by means of syphon pipes. The first section fills and discharges to the second until the level is the same in both divisions. The two beds then fill together and discharge to the third; the liquid lowers again and so on until all sections are full. A syphon in the last bed then discharges the entire contents. By this lateral streaming, Adam's patent process, greater purification is obtained in a smaller area.

Reference has already been made to the unsatisfactory distribution of the sewage by the perforated troughs of the earlier installations. More even distribution and better æration are obtained by spraying the tank effluent over the bed, and several firms have placed apparatus for this purpose on the market. The Mather & Platt automatic revolving spreader showers the sewage over the contact beds for any fixed length of time. The sewage enters a long trough which revolves round a fixed centre. In the trough are openings for the delivery of the sewage as the spreader revolves. Thus an equal amount is rained on every square yard. They have also a form for travelling in a straight line over rectangular beds. The Adams-Hydraulics Co. also make a revolving spray distributor provided with perforated pipe arms which spray the sewage evenly over the area of the beds.

Baffle, or **Baffler**.—Something which is inserted in the course of movement of furnace gases, or of water to delay, and direct the current of gas or water in certain directions.

In the furnaces and flues of steam boilers baffles or bafflers are often inserted, to throw the hot gases and flame against the most efficient heating surfaces. A fire bridge is a baffle, though not so termed. In some water-tube boilers baffles of brick are built in the furnace. The reason is that the cross-section is large where the gases leave the grate, and therefore the baffles are introduced to reduce the section, and increase the length of the traverse of the gases among the nests of tubes. In some cases baffles of sheet metal are inserted in the steam drum, to prevent the water from coming over with the steam from the headers. The baffle then fulfils the function of a separator.

The plate which is riveted two or three inches within the inner face of the furnace door of a steam boiler is termed a baffle. It distributes the air that enters through the grid openings in the door, and it prevents the latter from becoming buckled by the heat. The air space between serves as a protection.

Bagasse, or **Megass**.—A fuel used in the sugar industry, for the consumption of which special furnaces are built. It is not chosen as a fuel by preference, but is used in order to get rid of it. It is the refuse of the sugar houses, which would otherwise accumulate, and is therefore burnt to get it out of the way.

Bagasse is the cane from which the saccharine matter, to the extent of 70 or 75 per cent., has been extracted, leaving a crushed mass, comprising the woody fibres, and some sugar, which when dried forms a fuel. Special furnaces have to be constructed to burn the green bagasse. The heat generated is used for the boilers, vacuum pans, and other purposes, and it is employed thus to economise other fuel, or to displace it entirely. The bagasse furnaces are of large capacity, and are usually built of brickwork, the refractory character of the material intensifying the rate of combustion. There are three classes of these furnaces—the natural draught, the hot, and the cold air forced draught types, the last being the best. In the hot blast the air for combustion is forced through heaters, which are heated by passing the flue gases around them, as the latter travel from the furnace to the flues of the boiler which they heat.

A conveying plant is installed to carry the bagasse from the floor to the hoppers at the tops of the furnaces, into which it is dumped to pass into the brick combustion chamber. The water-tube boilers are admirably adapted to the utilisation of the heat from the burning of bagasse. The illustration, Fig. 44, shows a Babcock & Wilcox boiler so heated.

Bag Scoop, or **Bag Spoon**.—A crude device frequently employed in dredging shallow canals and streams, where the cost of a dredger boat, or of chain grabs would be prohibitive. A bag of leather with a mouth formed of a metal ring, and sharp on its lower edge, is used, or a spoon of metal, and these are dragged along the bed of the stream by a rope, or a handle, scraping up the mud or sand. Being lifted by a rope or a windlass the contents are thrown into the mud boat, or on to the bank as the dredging proceeds.

Bag Work.—A branch of concrete work in which the concrete is emptied in a semiliquid state into jute bags and then deposited in the sea. Its value lies in hard uneven beds, the alternatives to which would be expensive dredging, or blasting. The bags accommodate themselves to the contour of the ground, and their upper surfaces afford a fairly level basis

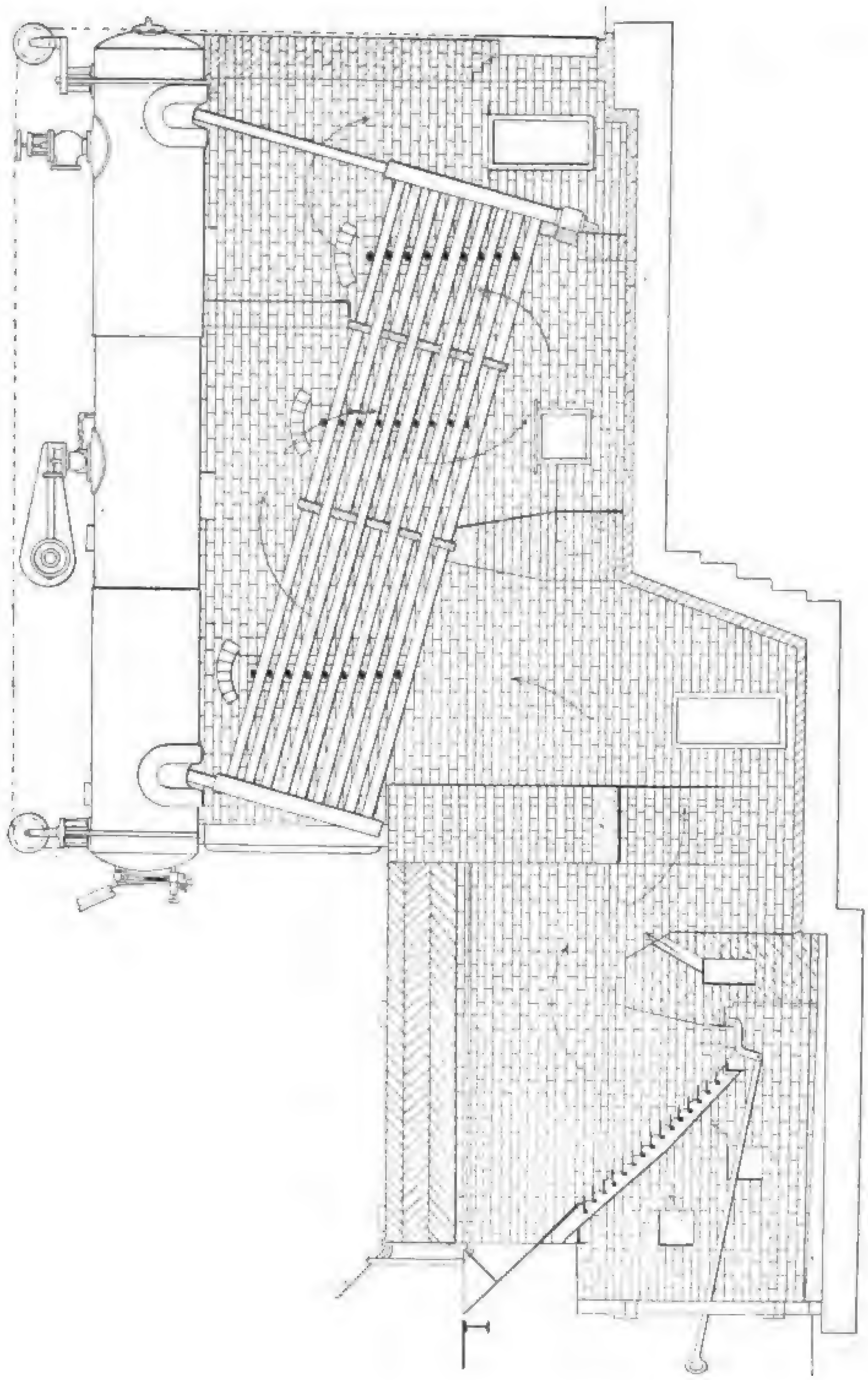


Fig. 44.—Bagasse Furnace

on which concrete blocks can be built. The development of the system is due to Mr Cay who has carried it out in many harbour works. It has also been adopted by other engineers. The concrete for bag work requires to be mixed well, and rapidly in order that it shall set uniformly throughout. Bag work requires a plant of its own. The continuous mixer system is necessary. Either side, or drop-bottom skips of large dimensions are necessary for the deposition of the bags.

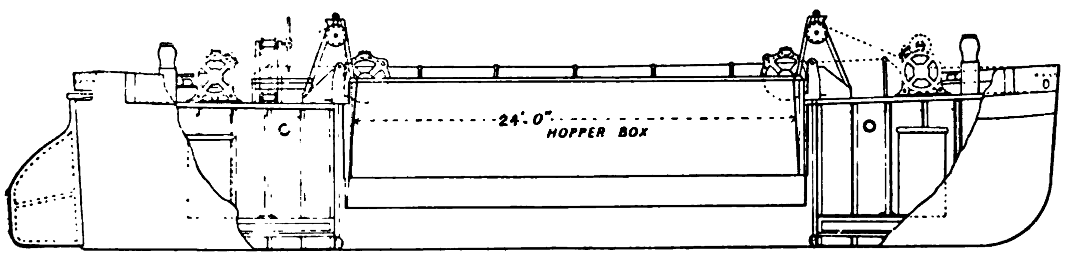


Fig. 45.--Hopper Barge for depositing 50-ton Concrete Bags (William Dyce Cay, Esq., M.I.C.E., Engineer). (Sectional Elevation.)

The first important application of the system was made by Mr Cay on the Aberdeen breakwater works, carried out by him from 1870 to 1877.

At the South Breakwater the foundation was in stiff clay with boulders, and instead of excavating a level bed, it was found to be better to make one up with concrete bags, which were deposited by iron skips holding 5 to 16 tons each. Also the toe of the foundation of the outer side which is exposed to very violent waves, was protected by a row of 100-ton concrete bags, laid longitudinally along it. The bag was placed in a large pine box above its intended site, and when it was filled and its mouth sewed up, a trigger was drawn, the bottom of the box swung open, and the bag fell through the water into its place.

A further application of this method was made at Aberdeen on the North Pier extension works, in 1874. The difficulties here due to the force of the waves were great. A case is given of a block of concrete 70 tons in weight, which was lifted from its bed and carried bodily by the sea to a distance of 50 yards into the harbour, where it was left stranded, and had to be removed by quarrying and blasting. The site was of boulder clay covered with a bed of shifting sand of from 3 ft. to 5 ft. deep. The end of the old pier, the extension of which was undertaken, was formed of rubble and stone pitching held together by iron bars. The boulder clay and the old rubble of the existing pier head formed an uneven surface which afforded an excellent test of the value of the new method of deposition. A novel method was designed by Mr Cay for this work, viz., depositing the bags through the well of an iron hopper barge (shown in longitudinal and transverse sections in Figs. 45 and 46). A depositing box was fixed in the central well of the barge, holding 50 tons of concrete at 16 cubic feet per ton. Its hinged drop-bottom was in two portions, which were hollow caissons, and when opened they did not project beyond the bottom of the barge. The recesses at the sides of the well, seen in the cross-section, received the doors when opened, so that their inside faces came flush with the sides of the box, and thus offered no obstacle to the descent of the bag of concrete. The simple withdrawal of a pin by a lever freed the door at both ends simultaneously, when the weight of the bag of concrete opened them.

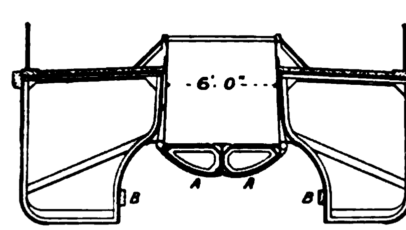


Fig. 46.—Midship Section of Hopper Barge, with Box.

The bags used for holding the concrete are of jute cloth, costing about 5d. a yard, and have

a longitudinal opening extending their whole length, with a flap. They are larger than the box, because they shrink when wet. The flap being thrown back, the concrete is filled in as mixed, the lid sewn over, and the whole deposited while green. The sewing of the flap confines the concrete in its descent. Six or seven bags a day were usually deposited thus.

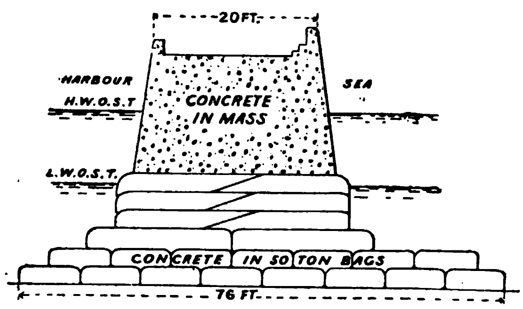


Fig. 47.—Cross-Section through North Pier Extension at Aberdeen. (W. Dyce Cay, Engineer.)

The concrete was composed approximately of 1 part of Portland cement, 3 of sand, and 4 of shingle. Fig. 47 gives a section through the pier, the foundations of which were laid thus.

Other methods of deposition have been adopted. Fig. 49 shows a drop-bottom skip which was suspended from a crane. This was used at Lerwick Pier, a section of which is given in Fig. 48. In another case the skip was of the tipping type instead of drop-bottom, and the bags contained 100 tons of concrete. The alternatives to bag work are concrete blocks, and monolithic concrete work, neither being so well suited for uneven ground. *See* **Block Work, Monolithic Work.**

Baily's Metal.—The alloy used for the Imperial Yard of Great Britain, the Standard Yard of the United States Bureau of Weights and Measures, and for about forty-four copies supplied by the British Government to foreign governments, and various public institutions. It is composed of 16 parts of copper, $2\frac{1}{2}$ parts of tin, and 1 part of zinc, and is standard at 62° Fahr.

Balance.—An instrument for finding the mass or quantity of matter in a body in grammes, ounces, pounds, or any other selected unit. Modern balances have been brought to such a state of perfection, that few instruments of precision approach them in delicacy and accuracy in working. A good chemical balance will indicate even the addition of a tenth of a milligramme to a weight of 100 or more grammes. The ordinary type of balance consists of a lever or beam with its fulcrum in the middle. The fulcrum is a hardened steel prism termed a "knife edge," resting on a polished agate or steel plate. From the extremities of the arms two scale pans are suspended from hooks which rest on similar knife edges turned upwards instead of downwards. These knife edges reduce friction and the area of the surfaces of contact to a minimum. A needle is fixed to the beam and oscillates through a graduated arc, remaining at zero when the instrument is in equipoise.

The *sensibility* of a balance depends on (*a*) the position of its centre of gravity—the nearer this is to the point of support the greater the sensibility of the balance; (*b*) the weight of the beam—sensitiveness increasing with its lightness; (*c*) the degree of freedom of friction between knife edges and planes; (*d*) the length

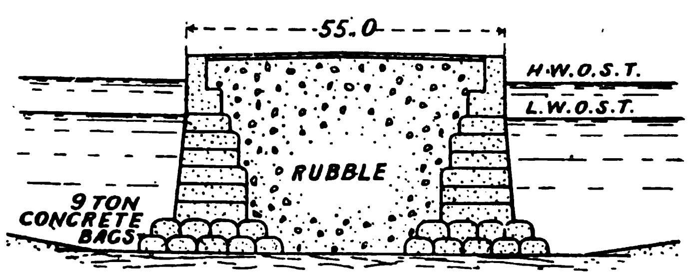


Fig. 48.—Cross-Section of Lerwick Pier.

of the arms — sensitiveness increasing with length, other things being equal.

The *accuracy* of a balance depends on (*a*) the equality in length of the two arms of the beam; (*b*) the position of the point of support in relation to the centre of gravity—the latter must lie vertically under the fulcrum when the beam is horizontal. The scale pans must also obviously be of equal weight.

When great accuracy is required, or when a

balance is defective in any of the essentials mentioned above, recourse is had to the process known as "double weighing." The body whose weight it is required to ascertain is placed in one pan and balanced with shot or sand placed in the other pan. When perfect equilibrium is obtained the body is removed and replaced by known weights. Then no matter how false the instrument may be, the true weight is correctly ascertained as the same effect is produced under identical circumstances. The commonest defect in a balance is inequality in the length of the arms. This is discovered and remedied by the "method of reversal"—or weighing the object first in one pan and then in the other. If the weights are similar the balance is true; if the weights are unequal the geometric mean between the two quantities will give the true weight. This is found by multiplying the two weights together and taking the square root of the product.

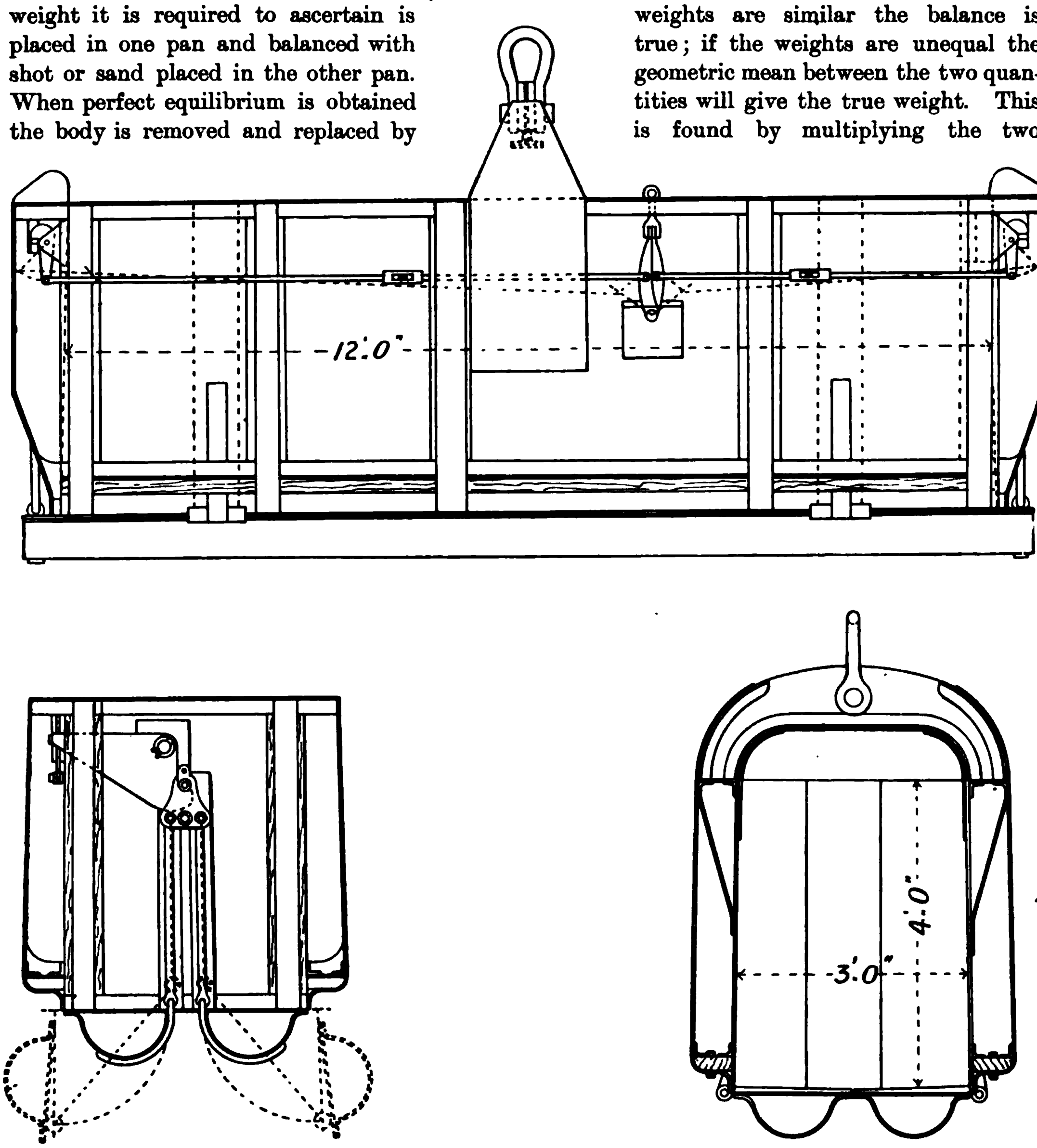


Fig. 49.—W. Iron Skip for 9-ton Concrete Bags. (W. Dyce Cay, Engineer.)

In the Roman steelyard the beam is movable about a fulcrum or knife edge at one end. The body to be weighed is suspended from or

placed in a pan depending from the extremity of the short arm while a known weight is slid along the long arm until equilibrium is obtained. The long arm is graduated so that the weight of the body is immediately seen. In what is known as the Danish balance the load and weight are placed at the extremities of the beam, while the suspension loop is moved along until the beam acquires a horizontal position, the weight of the goods being to the weight of the bob as their respective distances from the suspension loop.

In addition to the two forms of Balance just described there are also various kinds of Spring Balances which all act on the principle of stretching a spiral spring. The commonest form is that known as Salter's Balance, and is too well known to call for any detailed description. Obviously this type of balance can lay no claim to very great accuracy. *See* **Weighing Machines.**

Balance Box.—The box fitted at the rear of a hand balance crane to receive the kentledge or weights used for counterbalancing the mass of the crane in front of the central post, and of the load lifted. The mass of the crane behind the post is not sufficient to effect this without such extra loading. In steam or electric cranes the boiler, or motor, or sometimes the engines or heavy gears are located there to lessen the amount of extra balance required.

Balance boxes are fixed, or adjustable. If fixed they are bolted down at the extreme end of the tail. If adjustable they are mounted on wheels to be run inwards or outwards by means of a screw to suit variations in loads lifted.

Balance boxes are made of cast iron, or are plated. Those in cast iron are made either in one piece, or in five plates bolted together, comprising sides, ends, and bottom. Plated boxes are used chiefly for breakdown cranes, and for foreign orders. With the last exception there is no advantage in keeping weight down in boxes, the object being to obtain several tons weight at the rear of the crane.

Balance Chamber.—A compartment in a Whitehead torpedo enclosing sundry apparatus for controlling the proper and regular depth of movement of the torpedo in the water. The mechanism of this chamber, devised in 1868, was at first kept a profound secret from all except the officers who went through the necessary course of instruction.

The mechanism comprises a hydrostatic valve which can be adjusted by a compressed spring, the amount of compression being shown by an indicator outside the body of the valve, marked in feet. The valve is forced in by the pressure of the water when the torpedo goes beyond a certain depth. There is also a pendulum weight which swings fore and aft, and being connected by rods to the rudder controls the movement of the latter. The action is as follows:—

If a torpedo goes beyond its proper depth, as may happen when it first leaves the tube, the pendulum weight will move forwards, and the hydrostatic valve will be forced inwards against the compression of the spring. By means of a series of connecting levers the rudder is lifted hard up, bringing the torpedo upwards.

The chamber also contains several valves through which the compressed air passes from the air chamber to the engines. These are the stop-valve, the object of which is to prevent serious leakage of air while the torpedo is charged. The charging valve, which is also a non-return valve, through which air enters from the charging reservoir to the torpedo. The starting valve, by which the air is admitted to, or shut off from the engines. The delay valve, the object of which is to prevent the entry of air to the engines during the brief period in which the torpedo is passing from its tube into the water, and without which the propellers, in the absence of the resistance of the water, would revolve at about 2,000 revolutions per minute. The reducing valve, which ensures a uniform pressure of air to the engines throughout a run.

Balance Crane.—A crane in which the mass due to the load lifted, and that of the crane in front of the centre of the post, is counterbalanced by the mass of the crane behind the centre, plus an extra weight or "balance" located on the tail girders of the crane. Stability is thus imparted in the act of lifting and lowering, since the crane would upset if no balance were fitted.

Balance cranes are either **Fixed Cranes**, or **Portable Cranes.** In the first case the post

is fixed in foundation plates, in the second it is set in a truck travelling on wheels, which are generally, though not invariably flanged to run on permanent way. When a crane is portable, the question of stability of the truck has to be considered in estimating the effects of the balance weights. *See* **Blocking Girders**, and **Rail Clips**. Balance cranes are operated by all the usual agencies, by hand, and by power, steam, hydraulic, compressed air, and electricity. A form of balance crane is constructed for use on permanent way, being then termed from its special functions, Accident Crane, and **Breakdown Crane**. Numbers of balance cranes are distinguished by other names, in which balance, though not stated, is understood to be present.

The stability of a portable or travelling jib crane is primarily determined by calculation. The condition to be secured is that the centre of gravity of the crane, load, and ballast shall lie within the base of support; this base of support is ordinarily limited by the gauge of track and by the wheel base of the carriage, but it can be extended by means of Blocking Girders. If a crane is designed so that its centre of gravity lies outside of the gauge, then blocking girders or Rail Clips must be resorted to. Of late years, requirements demand cranes capable of handling their maximum loads safely in any position, and travelling with the same freely upon the track; consequently the custom of blocking up a crane is not so much resorted to as formerly, the net result being that cranes are built heavier. There are two definite calculations involved, one to determine the stability of the crane with the load suspended, the other to assure that the crane is stable backward when the load is removed.

Assume the case of a crane, Fig. 50, to lift a load of 3 tons at a radius of 16 feet, on a gauge of 4 ft. $8\frac{1}{2}$ in. The forward tipping moment is found by multiplying the weight:—3 tons, by the distance that it overhangs the rail = 16 ft. minus half the gauge, 2 ft. $4\frac{1}{4}$ in., say 2·4 ft. = say 13·6 ft. × 3 tons = 40·8 foot tons. The next step is to assess the margin of safety, and this depends upon the size of the crane and the nature of the work; for cranes up to 10 tons capacity, with radii up to 20 feet, a 20 per cent. margin is ample for ordinary work, for cranes with long jibs and high gantry carriages the allowance may rise to 50 per cent., whilst for high speed cranes working in exposed positions, such as harbour portal cranes, a margin of 100 per cent. is demanded in first-class specifications. In the present case a 20 per cent. will be satisfactory—this quantity is to be added to the tipping moment, giving a total of

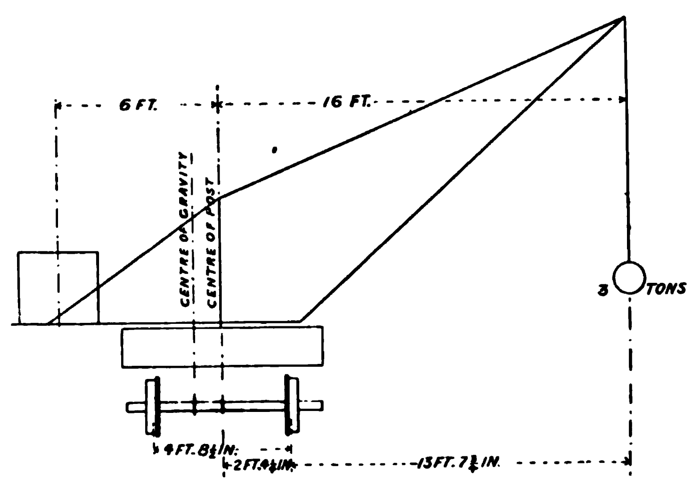


Fig. 50.—Diagram to illustrate Stability of Balance Crane.

$$40{\cdot}8 + \frac{40{\cdot}8 \times 20}{100} = 48{\cdot}9 \text{ foot tons to be balanced.}$$

Now a steam crane of this capacity will weigh about 15 tons, and its centre of gravity will be about 12 inches behind the centre line of the pivot, giving a total backward moment about the front rail of 1 foot plus half the gauge, 2·4 ft. = 3·4 ft. × 15 tons = 51 foot tons, a quantity slightly in excess of the forward moment of 48·9 foot tons as calculated above; such a crane is therefore quite stable both forward and backward, for the centre of gravity being 12 inches behind, the centre is still 1·4 foot inside the back rail.

If the case of a hand crane were investigated upon the above basis, a different result would be obtained; a hand crane would not exceed

8 tons in weight, if built on usual lines of construction, and its centre of gravity would be practically on the centre line, giving a total backward moment of 2·4 feet × 8 tons = 19·2 foot tons; subtracting this sum from the forward moment of 48·9 foot tons, a moment of 29·7 foot tons is found to be still unbalanced, and the crane is therefore not stable, but by adding ballast to the tail of the crane this deficiency can be made up. With a tail radius of 8 feet, and a centre of ballast weight of say 6 feet from the crane centre, the total effective distance from the front rail is found to be 8·4 feet; dividing this figure into the unbalanced moment we obtain $\frac{29 \cdot 7}{8 \cdot 4} = 3\frac{1}{2}$ tons of ballast required to maintain stability.

Now it is necessary to enter upon the second calculation and ascertain whether the crane is going to be stable backward when the load is removed. The backward moment is the weight of the ballast, $3\frac{1}{2}$ tons, multiplied by the distance it overhangs the rear rail = $3\frac{1}{2}$ tons × 3·6 ft. = 12·6 foot tons plus a 20 per cent. margin = 15·1 foot tons to be balanced by the crane; the moment of the crane itself inside the rail is 8 tons × 2·4 ft. = 19·2 foot tons; the crane is therefore stable backward. If in the case of this hand crane we had attempted to do the same duty on a 3 ft. 6 in. gauge we should have found that so much ballast would be required as to render the crane unstable backward when the load was removed, unless we added weight to the crane itself, but in such cases it is usual to provide blocking girders, and to mount the ballast on wheels, the object of which is to move the weight nearer to the crane centre when not in use, and so reduce its overhang to a safe limit when the blocking girders are not in use.

Balance Cylinder, Balance Piston.—A device employed in large vertical engines, using common slide valves, for relieving the eccentrics of the weight of the valve, valve gears, and rods, which would wear the upper half of the eccentrics more than the lower. It comprises a small cylinder, Figs. 51 and 52, in the top of the valve chest, having a piston on an extension of the valve rod, and the area of which is calculated for the pressure necessary to balance at the pressure in the chest. The upper part of the balance cylinder of the high pressure valve is connected to the receiver, that of the low pressure to the condenser. An alternative method is to put the balancing cylinder outside the valve chest, and supply steam direct from the boiler to the under side of the piston.

A balancing cylinder is fitted to some hydraulic lifts, separate from the main cylinder. It is placed in any convenient situation near the lift, to which it is connected with a pipe.

Balanced Cranks. — It is necessary to counterbalance the weight of the cranks of high speed engines by means of counterweights on the opposite side of the axle. Half the length of the connecting rod is also usually included in the balance.

Balanced Slides. — *See* **Balanced Spindles.**

Balanced Slide Valve.—A slide valve which is fitted with some device for relieving the valve in part of the resistance due to the excessive friction on its working face. This is due to the pressure of the steam on the back, which is only slightly counterbalanced by that in the ports. At certain stages it is not counterbalanced at all. As pressures increase, the friction becomes more serious. Moreover the pressures vary constantly, which is the reason why the usual plan of designing the valve for a constant area of relief on the back is not entirely satisfactory.

Two principal devices are employed to balance the valve; one an equilibrium ring, Fig. 51, the other a relief frame, Fig. 52. The first is the older method found in numerous designs on engines of twenty and thirty years since. The ring is recessed into the internal face of the steam-chest cover, and is forced on the back of the valve by means of set screws, the resistance of which is taken by springs. The back of the valve makes a steam-tight fit with the ring, and the space enclosed holds a vacuum which is connected to the condenser. The area of the ring is made about equal to that of the exhaust port.

The modern method is to fit a relief frame, either to the back of the valve, or to the inside of the steam-chest cover. In the first case the frame moves with the valve against the face of

the steam-chest cover, in the second the back of the valve slides against it. The essential mechanism is an elastic diaphragm plate of spring steel, by means of which pressure is ensured, and compensation made for wear.

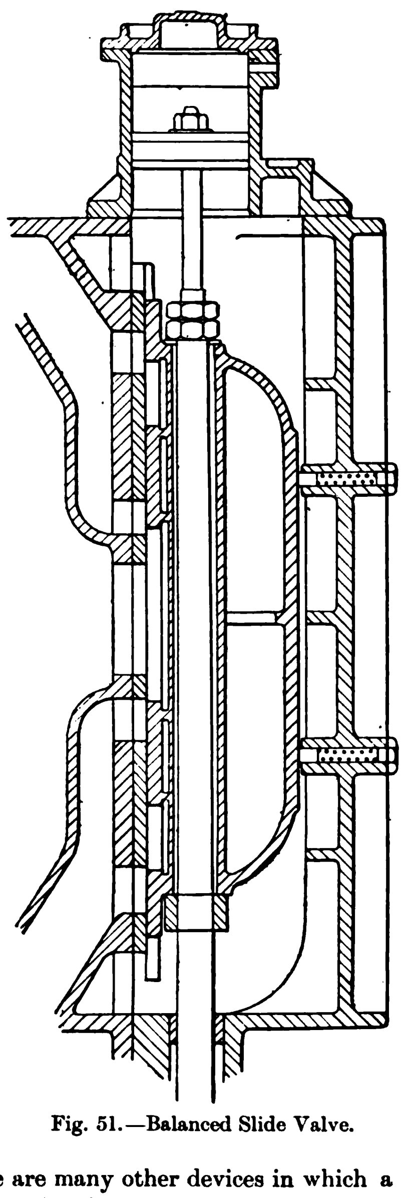


Fig. 51.—Balanced Slide Valve.

There are many other devices in which a relief ring is fitted piston-like into a cylindrical socket.

Valves which are self-balancing, are cylindrical in shape, and are termed **Piston Valves.**

Balanced Spindles and **Slides.**—It is necessary to counterbalance the mass of vertical spindles and slides used in drilling, and milling machines in order to lessen the work of lifting them. This is now done far more commonly

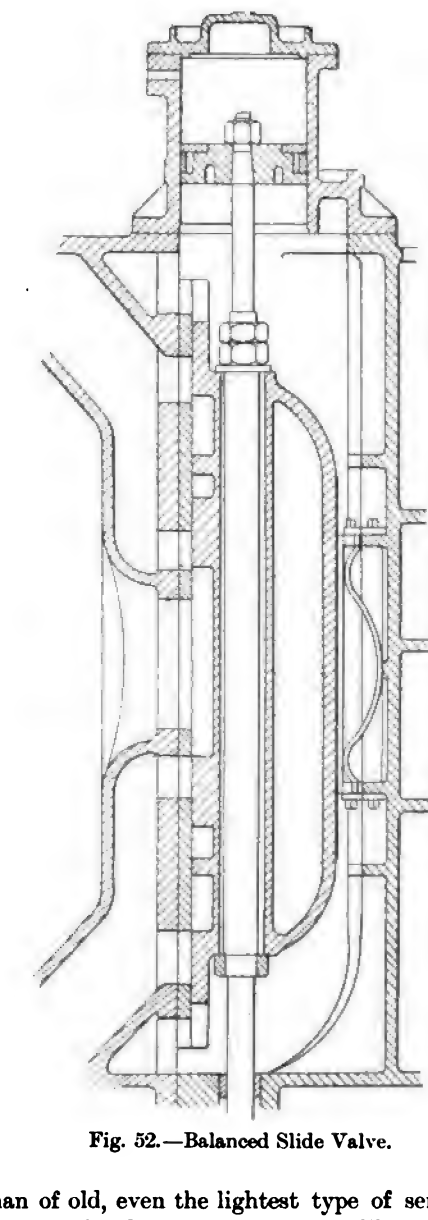


Fig. 52.—Balanced Slide Valve.

than of old, even the lightest type of sensitive drill spindles being thus treated. The methods of balancing vary. In the case of the drilling machines just mentioned, and in some light milling machines a coiled spring is the device adopted. In the heavier machines weights are

used. As these cannot be in line with, or adjacent to the spindles, like springs, they are suspended in any suitable location, and connected with the spindle or spindle slides by means of chain or wire rope passing over a guide pulley. Neatness is studied in many designs, the weight being placed within the framing of the machine, and invisible, instead of without. In many of the older machines spindles were counterbalanced by means of a lever and counterweight, a device which is not adopted so much now. These devices are also applied to vertical boring mills, slotters, various grinding machines, &c.

Balanced Valves.—A type of hydraulic valves used for high pressures in which the power to open the valve is reduced to a minimum by an arrangement of pistons. Some of these are balanced in one direction only when water has to flow in one direction, others in both directions as when the water must flow both ways.

Balance Weight.—A number of articles are included in this general term. The balance weights of a crane are put both into the **Balance Box**, and in the tail behind, or under the boiler to afford additional counterbalance to the mass of the crane, and its load in front of the post. Such weights vary in the same type of crane, with the radius of jib. Balance weight also denotes a movable type of crane balance, which is self-adjusting with variable loads.

Balance weights are fitted to brake levers, to pull them back into place on the removal of the foot or hand. A jockey weight is a balance weight, the object of which is to produce equilibrium.

Balancing.—If a disc, a pulley, a drum, or a gear wheel is rotated on its shaft it will, if heavier in one portion than another, wobble and bend the shaft, if the shaft is light enough to be bent; if not, then vibration will be set up, and a tremor will be sensibly felt. An extreme case is afforded by the long drums that are used to drive some machine tools with traversing heads, and by double-armed pulleys, and wheels the shafts of which are insufficiently supported by their bearings, due to the latter being situated too far away. Bearings then become hot, and shafts are permanently bent, or broken.

Good balancing is so important in these cases that all pulleys for high speeds must be tested and corrected until the centre of gravity is made to coincide with the axis, instead of falling to one side of the same, as it obviously does when one portion of the pulley radially has more mass than other portions. Generally then, metal is removed by drilling or other means rather than by adding metal.

To balance belt pulleys, a pair of trestles are rigged up. The pulley to be tested has a mandrel fitted to its bore, with journal-like ends standing out, which ends are supported on steel knife edges carried on the trestles. The pulley rim must be true with the bore, of which, if there is any doubt, the mandrel should be centred in the lathe, and run round by it, and the rim corrected if necessary.

On revolving the pulley by the journal ends on the knife edges, it will, if unbalanced, come to rest in one position, heaviest side downwards. If a suitable definite mass is put directly opposite this, the pulley will be balanced. But if the pulley is divided into three equal parts, starting from the heaviest section, and mass added at the other two sections, the weight will be more equally distributed. The best method of testing the added weight required is by means of lumps of soft clay, stuck on, and then weighed.

In the case of cast-iron pulleys, holes are sometimes drilled in the heavier portion. Often the want of balance is mainly due to a defect in the casting, a local lump, and then the better way is to chip this off. When practicable, the best plan is to turn the inside of the rim as far inwards as the arms, or for a portion of the distance. In wrought-iron pulleys pieces are riveted to the inside of the rim, or attached to the arms adjacent to the rim. In the case of pulleys cast in halves all the actual bolts to be used must be inserted. It will often be possible to balance these by chipping or machining metal from one of the split lugs.

At very high speeds, of several thousand revolutions per minute, the problem of balancing becomes more difficult. There is what is termed a critical speed at which, in unbalanced wheels,

the axis of rotation changes momentarily. The case of long drums is more troublesome than that of narrow pulleys, because in the former extra weight may occur near one end, or at opposite ends in unequal amounts, and so complicate the movements. Methods of ascertaining the position and mass of counterweights required in such cases have been devised. One is that of discs, one at each end of the shaft, and flanking the drum or cylinder. The discs have holes for the attachment of balance weights, and they are slid round the shaft until a location is found at which the weights on the disc counterbalance the part of the drum that is out of balance. Another device was that of Messrs W. Sellers & Co., in which three eccentrics 120° apart were mounted on the shaft by a frictional fit only. In the act of rotation of the discs which were being tested the eccentrics worked round, and took up positions which brought them into perfect balance with the discs.

Balancing, as applied to locomotives signifies the means taken to counteract the damaging effects of otherwise unbalanced revolving parts, and also of reciprocating parts. The first-named includes the cranks in inside cylinder engines, the crank pins and their bosses in outside cylinder engines. The reciprocating masses include those which receive their movement from the crank axle, namely, the connecting and the coupling rods, the masses of these being considered as transferred to their respective crank pins. The practice is to balance these masses by placing, or casting revolving weights in the wheels, the weight of which is sufficient to compensate for the effects due to both the revolving and the reciprocating parts.

Whether to balance the whole of these masses or only a portion has always been a matter open to discussion. General practice favours taking two-thirds only of the reciprocating masses for balance. In strictness as much as possible should be balanced, but many cases have arisen of overbalancing, resulting in excessive straining and wear, in severe hammer blows, and in rail fractures. At the other extreme there are numerous cases of the weights being reduced, and sometimes of their being removed entirely with advantage in some cases, or without detriment in others.

This is a general statement of the method of balancing, but particular cases have to be decided by the character of the engine, whether with single drivers, or four, or six coupled. Also by the position of the cylinders, whether inside, or outside. It is complicated by the hammer blow, a term which denotes the variation of the pressure between the wheel and the rail, caused by the vertical component of the centrifugal force, due to that portion of the balance weight which is balancing the reciprocating masses. This variation is not so sudden as the term would imply, yet it may in some extreme cases be of a serious character.

In single driving wheel engines the balance weights are put in the driving wheels only. In coupled engines it is better to divide the balance weight for the reciprocating parts between the coupled wheels. This has the effect not only of affording a suitable balance, but it also reduces the variation in the rail pressure in a very large degree. It has also been found to reduce the wear and tear of the coupling rod bearings.

With regard to overbalancing it has been found that it produces unequal wear of the tyres. Also, with inside cylinder engines, the irregularity of pressure produced on the main bearings has resulted in unequal wear, producing an elliptical form. The question is one of even greater importance than formerly because of the increase in the size and weight of engines. It is also rendered difficult by the wear of the wheels and bearings, which cause unequal and varying and incalculable stresses to be thrown upon the coupling rods. Calculations go upon the assumption that each coupled axle takes its due share of the work, whereas that cannot be uniformly true.

Good practice recognises and adopts the following, subject to variations to suit special conditions. With single drivers, two-thirds of the weight of the reciprocating parts is as much as can safely be balanced in the driving wheels. Rather more, and often the whole mass of the reciprocating parts is balanced in coupled engines, being distributed equally between the driving and the coupled wheels. Revolving

besides the cranks, as the weight of the pistons, and rods, of the valve gears, and certain rocking vibrations which are due to the corresponding of separate engine units working on the same crank shaft situated at certain horizontal distances apart. Mr Yarrow's experiments have shown that this last is a more serious cause than the vertical vibrations. It is of a different character again in double cylinder engines with cranks at right angles than with triples. In a single cylinder engine, only the up and down motion is present. The latter in any type is compounded of two motions, that of the cranks, crank pins, and connecting rods; and that of the pistons and rods, &c., which are distinct; the first being of a rotary character and the second consisting of the unbalanced weight of these elements. In compound and triple expansion engines these last not only cause vertical vibration, but produce a constant vertical motion or change in position of the centre of gravity of the engines as a whole, due to the difference in weight of the working parts of the separate engines. The general effect of the motion of the pistons is to alternately tend to lift, and thrust down the engine bed, and with it the hull.

It is possible to neutralise all these unbalanced forces by the use of weights suitably distributed. Every unbalanced portion of a set of engines is dealt with separately, and the position and amounts of the weights may be separately located, or as is more commonly done, massed in larger weights, and located as most convenient, nearer to, or farther from the centre of the crank shaft, with their mass in inverse ratio to their distance from the centre. Mr Yarrow proposed a system of bob weights operated by eccentrics to impart an up and down motion to the weights.

Balancing of swing bridges is necessary when the pivot is not in the centre of the bridge as is most often the case. A short tail is adopted for two reasons, one being the saving of expense, counterbalance costing less than bridge work, and the other for the same reason that short tails are fitted to cranes—to economise valuable space. A usual proportion is about one-half of the forward portion.

The extra weight is put in a ballast box at the rear, below the floor. The term kentledge is applied to this, as also to the contents of the balance boxes of cranes, and it usually takes the form of cast-iron weights of any convenient size suitable for insertion. These are cast of the merest rubbish in the yard, burnt iron, or any stuff that can be got to run. Sometimes rubble is used, or gravel, but a larger space is wanted than when iron is employed.

In plate mills the top roughing roll is balanced by counterweights.

Revolving cranes have their jibs and loads counterbalanced. *See* **Balance Crane**.

Counterbalancing is applied to lifts, in some cases by weights, in others by means of a second hydraulic cylinder.

Balancing Way.—The trestles or other rig-up on which pulleys, drums, and wheels are balanced. The Bowsher Way is an article of manufacture which has several advantages over an ordinary apparatus. The balancing standards are carried on a frame with three legs, the height of two of which is adjustable by screws, and the frame carries a spirit level. One of the standards is fixed, also with a spirit level, the other is movable towards and away from the fixed one, on planed ways. The top knife edges of the standard are chilled and ground to receive the mandrel in the work.

Bale.—A quantity of material which being of a fibrous or loose character in its natural state is pressed into a small compass for convenience of transit and storage. *See* **Baling Press.**

Baling Press, or **Dumping Press.**—A hydraulic press the special function of which is the compressing of loose materials into rectangular bales, of dimensions convenient for shipment and storage. The device is adapted for many different kinds of materials, and the industry has developed into large proportions. Among the articles so baled are esparto, fibre, fodder, hay, hides, hops, linseed, rags, scrap iron for balling, tea, and wool.

The foundation of any baling press is the hydraulic ram, see Fig. 53. This is placed with its cylinder below the ground level, and actuated from a hydraulic force pump adjacent. The top of the ram carries a broad table or platen which rises with its movement. Underneath the table a strong, deep, rectangular bed

surrounds the cylinder and carries stout pillars to which the crosshead is attached above. This head receives the pressure transmitted from the rising table through the bales. Though each one of these details in a baling press is varied, these are the essential elements. A few variations will be noticed as we proceed.

An important part of a baling press is the box, or boxes, used for retaining laterally the material which is undergoing compression vertically. These are made of wood braced with hinged corners, and having clamps which are faced with wood having grooved faces through which the hoops are passed for binding the bales round. The pressure amounts to about 2 tons per square inch, and six trusses can be compressed into the compass of one. Bales that have been imperfectly compressed by screw pressure in the country are further squeezed in hydraulic presses.

Some presses which do not use boxes are fitted with solid continuous wooden sides, and with movable retaining vertical bars at front and back, the bars being hinged in lugs, and retained

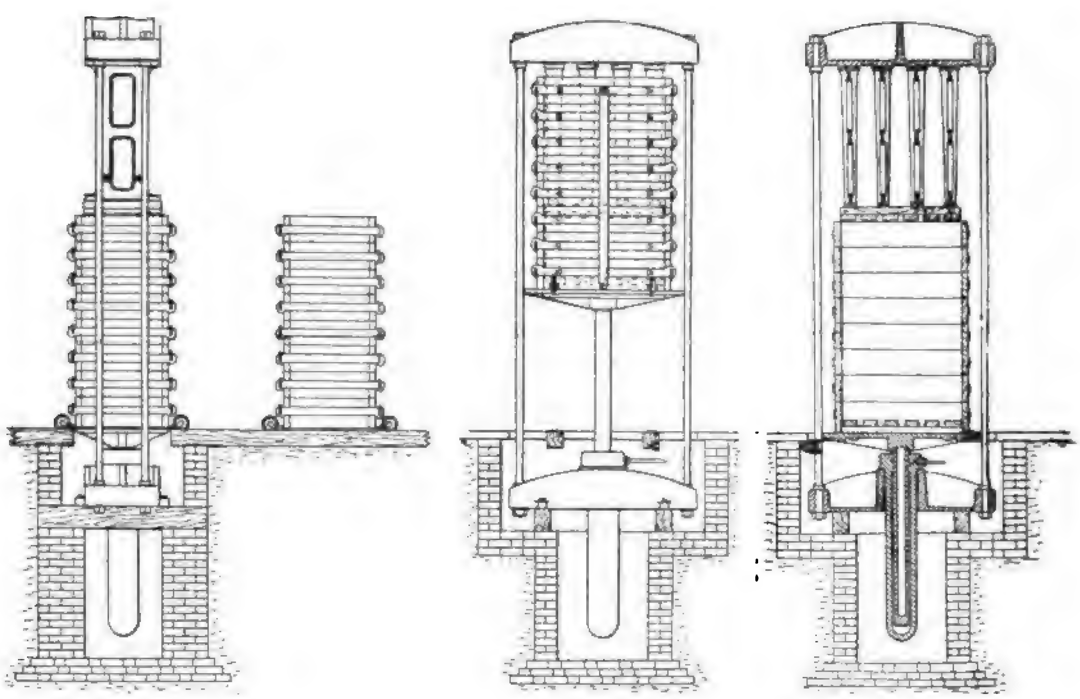


Fig. 53.—Baling Press. (Hayward, Tyler, & Co., Ltd.)

are closed before the squeezing commences, and opened when the operation is done, so permitting the box to be drawn away from its bales. The depths of the boxes vary with the character of the material. In some cases the boxes are made of steel to resist great lateral pressure.

In others no boxes are wanted, as in pressing blankets, and cloth, or hay already in truss. For loose hay, boxes are required, as also for cotton or wool. When trusses are compressed, the table, and head of the machine with set pins. In other cases bars are placed at sides and front and back. In some presses the head is not fixed at the tops of rigid pillars, but may be slid on the pillars and adjusted at various vertical positions to suit the depth of bale being pressed. There is a form designed to suit pockets of hops of different thicknesses.

Some duplex presses are made with continuous sides of sheet iron and movable bars at front and back. The table and head are grooved for hoops, and either two bales or one can be used. Hide presses have loose bars

at front and back. A useful adjunct to some of these is a long winding roller of hexagonal shape at each side, flanking the rising table, around which the rope is wound for tightening round the bale as the pressing proceeds. The rollers are turned by handspikes, and ratchets prevent backward slip. When neither boxes of wood nor loose bars would be suitable, boxes of steel, either plated or cast, are employed. These are used for liquorice root, and for dry fodder.

An adjunct to many of these presses is a line of rails for running the boxes to and away from the machines, in the same style that is common in many moulding machines used in foundries.

There are many presses which, though they are not used for baling, are simply adaptations to suit other work. Thus, it only needs a different arrangement of boxes, or the substitution of other vessels, to render them suitable for extracting tinctures, the liquor from tanner's bark, and compressing the material for burning, for separating tallow from greaves, for pressing olives, grapes, hops, linseed, castor, rape, almonds, &c., and the extraction of the oils. Some of these combine an apparatus for delivering the pressed cake after the extraction of the liquid, the cake being thrust out below or above. Two rams are then generally fitted, one above and one below. In a more elaborate machine a revolving table is included in which two sets of dies are fitted, so that one cake of material is being discharged while the other is being pressed, a separate delivering ram being located under the table.

Other varieties of presses are those for stearine, with loose wrought-iron plates for placing between the cakes, and both in the usual vertical, and also in horizontal types. Cold and hot presses differ, the latter having double plates to permit the heat to pass through, and the whole enclosed in a steam chamber.

The amount of pressure exercised on goods varies in different materials, to which the area of the ram, and its pressure, and the area of the pile have to correspond. Both vary within very wide limits. A usual pressure is $2\frac{1}{2}$ tons per square inch, which should not be exceeded in ordinary presses and pumps. If higher are required, special designs are necessary to withstand them. The pressure per square inch on the surface of a material can be ascertained thus:—Divide the total pressure on the ram by the number of square inches on the surface of the pile, or the interior of the box in which it is pressed. Standard-sized rams usually range from 3 to 10 inches diameter.

Though the hydraulic press appropriates most of the baling work, yet for situations where water pressure is not available, steam cylinders of large piston area are used. Tea presses are made thus, with the cylinder overhead, and two piston rods move the table.

Balk, or **Baulk**.—A squared log of timber, either rough hewn or squared. The term is restricted to timbers of not less than 11 or 12 inches square in section, whence they range up to about 18 to 24 inches. Logs below 12 inches are "undersized."

Ball and Socket Joint.—The accommodating movements of a ball within a cup socket are utilised in many forms of joints, for transmitting shaft rotation, and for pipe joints, a hollow ball being used in the latter case. Ball fittings are also employed in cases where a flexible anchorage is required, that cannot be met by a plain eye bolt fastening. The end of the tie rod or bar is then fashioned into globular shape, and is retained with a cap in a cupped anchorage, that the bar may accommodate itself freely to changes of angle.

The type of ball joint which is used extensively on machine tools and similar service has the shaft ends provided with Tees, running in cross Tee grooves in the balls. These allow a limit of angling of about 70°. Other types are designed for such work, for which *see* **Universal Joint**.

Ball pipe joints are employed in place of flexible hose, being more durable than the latter, especially in severe service out of doors, in circumstances tending to rot and damage leather or other materials. Such ball joints are made tight by grinding, without the necessity of using packing.

Ballast.—Broken stone, brick, gravel, and other hard materials, in a loose condition. To the engineer the interest in ballast centres in railway work, in the formation of embankments,

or in the building of breakwaters and dock walls, and in permanent way.

The object of ballasting in permanent way is to distribute the load from the sleepers to the bearing surface of the formation level, or level of the earthwork. Ballast prevents the sleepers from shifting, it serves for drainage, and imparts a certain degree of elasticity to the railway.

The depth of the ballast is usually about 12 inches below the bottom of the sleepers, and it is often piled up round them to a greater or less amount. More depth is sometimes given in cuttings than elsewhere, to favour the drainage. The latter is a very important function of the ballast, because loose sand is not so suitable for the purpose as broken rock or gravel, which leaves interstices for the running away of the water. Besides this, sand, if used gets blown into the bearings of engines and axles, scoring them, and getting on the rails, increases the resistance to the train.

The materials for ballast are sometimes selected from those available locally. In some cases broken slag has been used. The pieces of rock or slag should not exceed from 2 in. to 3 in. in dimensions. Materials which become softened by the action of rain are not suitable; slate for example, or under-burned clay, become pulpy under the action of the weather, and lying closely to the sleepers prevent the escape of water, so causing the sleepers to rot. The cost of breaking stones or slag finely is sometimes avoided by placing the ballast in two layers, the lower portion of comparatively large pieces, the upper of smaller ones. Otherwise the same sizes of material are used throughout. The ballast is spread about 18 inches beyond the ends of the cross sleepers.

From the point of view of drainage it is better to lay the sleepers on the ballast, and not bring the latter up the sides. The Midland Company adopted this plan, but abandoned it on account of the noise set up. In shunting yards it is necessary to raise the ballast nearly to the level of the tops of the rails to prevent risk of the shunters catching their feet in the rails when getting under the buffers of wagons.

Ballast Crane.—Denotes no type of crane in particular, but is sometimes applied to cranes employed in loading ballast at wharves and docks.

Ballast Tanks.—Tanks of water sometimes hung beneath the tails of block-setting cranes. They serve the double purpose of assisting to balance the cranes, and of holding a supply of feed water for the boiler.

Ballast Wagon.—A railway wagon for ballast; usually the sides open and fall down, being hinged at the bottom edges. Hopper wagons are also made. Sides are of timber, as red deal, or of steel. Under frames are of steel. Bogie wagons are sometimes made.

Ball, Balling up.—Applied to the pasty mass of malleable iron produced in the puddling furnace before any mechanical work is done upon it. The term ball is given because the workman detaches portions of the metal, and rolls them into balls of from 60 to 80 lb. weight, on the bed of the furnace preparatory to their withdrawal by the tongs through the working door.

Ball Bearings.—The ball bearing substitutes rolling action for the sliding friction which takes place in plain journals, and on end faces. To obtain true rolling, several matters must be taken into consideration. What may be termed "clean" contact, on points or lines only, instead of partially around the balls, must occur; nothing must interfere with the pure rolling, and induce sliding friction, and the balls in a race must be of uniform size within very close limits. The first-named depends upon the design of the bearing, and upon its manufacture, since a soft yielding material will allow the balls to impress themselves partly into the races, and spoil the line contact. The uniformity of ball sizes is a question of manufacturing and gauging. If one or two balls happen to be larger than the rest, these oversized ones will take most of the load, damage themselves, often fracturing, and injure the races in which they run.

There are two main classes of bearings, those for taking end thrust, and those for circumferential running. The first may comprise balls rolling between plain flat-surfaced discs or plates, Fig. 54, A, or ones with concave grooves B, or Vee'd recesses C. The disadvantage of the first type is that there is nothing to restrain

the balls from wandering sideways, and a cage must therefore be provided to confine them. Sometimes one disc is recessed, to keep the balls true, frequently both are, as at B. The Vee'd form provides two points of contact for the ball on each race, but unless very carefully made, it gives rise to friction and sliding of the balls upon the races. It is obvious that if a Vee having sides of equal slope is made, one side of this slope must slide against the balls, because of the different rates of travel of the Vees at the small and the large diameters. By following the construction at C, where unequal radius at the bottom of the groove, with the idea of strengthening the disc.

The great care necessary to get these two-point bearings accurate is chiefly accountable for the greater favour which the single contact types enjoy, being more easily machined, and therefore cheaper to produce, while the risk of spoiling the pure rolling motion by inaccuracies

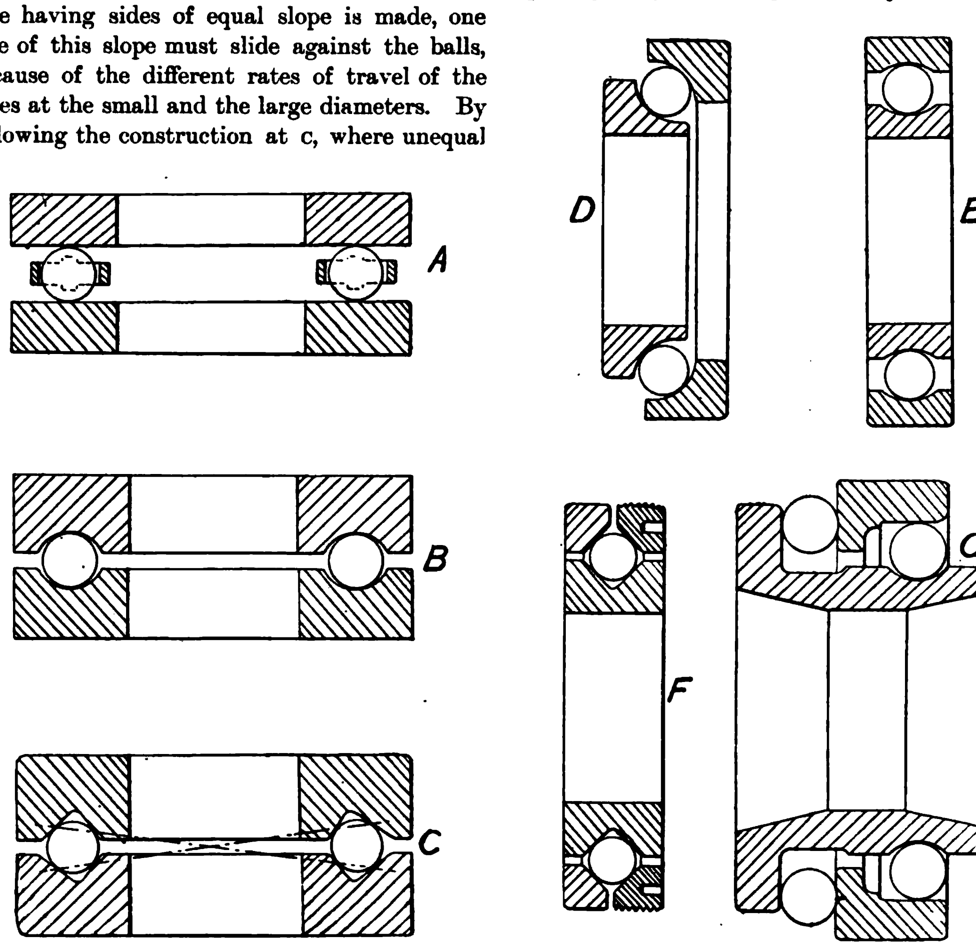


Fig. 54.—Examples of Ball Races.

slopes are employed, the balls touch upon points which lie in planes radially from the central axis, as shown by the dotted lines. This is the same method as that adopted for roller thrusts, which must be tapered radially, in order to accommodate the differing rates of movement of a disc from centre to outside. A modification of the Vee is made, having a considerable

is obviated. Referring to B, provided the centres of the concavities in the two discs come opposite to each other when mounted, the balls cannot do otherwise than roll without sliding. If one disc has a plain face, the balls adjust themselves naturally upon this, irrespective of whether the two discs are concentric with each other. In certain cases it is essential to fit one

... a concave face, so ... itself automatically ... give a true bearing ... of unequal pressure, as would be the case if shaft and housing were not in alignment.

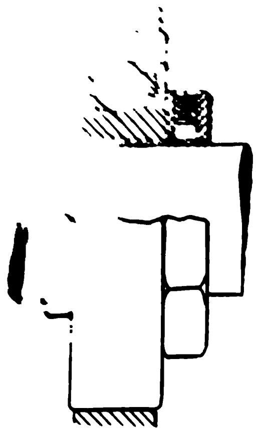


Fig. 55.—Shaft Bearing.

End thrust, and circumferential, or journal loads cannot both be taken by the same set of balls except in the design shown at D, which, however, is only suitable for light loads, though it may be run at high speeds. But in dealing with medium and heavy loads, a separate ring of balls is necessary for end, and for journal pressures, so that the loads come in direct line with the bearing points of the balls, which cannot be the case in the combined type at D.

The journal design takes the form of internal and external rings, the first being clamped to

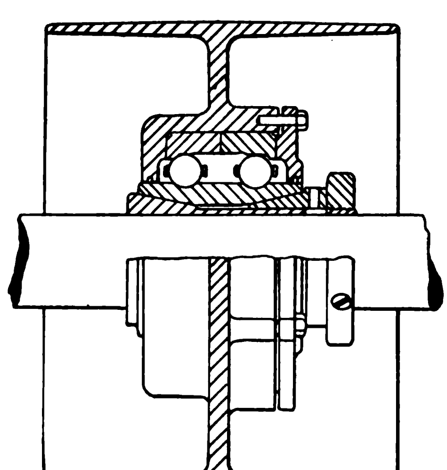


Fig. 56.—Loose Pulley Bearing.

the shaft, and encircled by the second. Either concave grooves E are provided, or Vee-shaped ones F. When the two conditions have to be met, a compound bearing must be employed, of which the Hoffmann type, G, is illustrated. Here it will be seen that the same internal ring which carries the journal balls is extended into a shoulder that forms one thrust face.

The illustrations, Figs. 55-58, show other applications of ball bearings by the Hoffmann Company to various purposes. The use of a cage to contain the balls is a development which has very extensive employment. It has two purposes—to prevent the balls from touching each other, and so causing sliding or rubbing friction, and to retain them in a

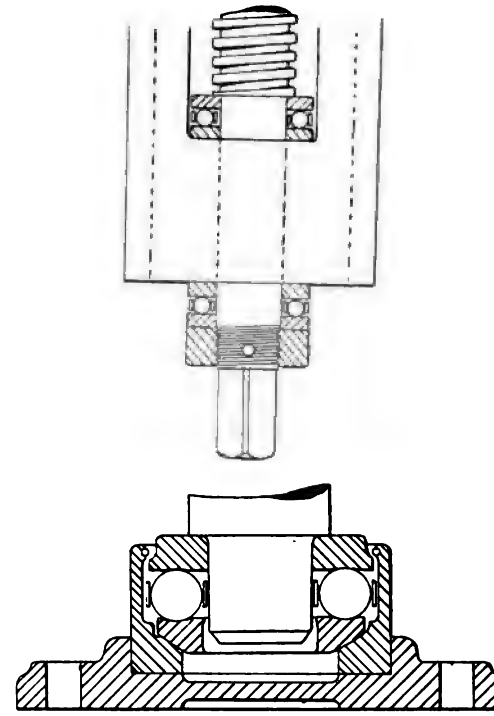


Fig. 57.—Thrust Bearings.

Upper Fig., thrust for slide rest screw. Lower ditto, footstep bearing.

whole set, which does not scatter when a bearing is opened. The cages, of which examples are noted in the drawings, float lightly upon the balls when running, without causing any friction worth notice. To further help in keeping each bearing a self-contained unit, a retaining wire is often used (*see* the Hoffmann illustrations, Figs. 57 and 58), which is sprung into a shallow groove in the outer housing, and projects sufficiently to prevent the upper

TABLE OF BALL BEARINGS, AUTO-MACHINERY CO., LTD.

Diameter of Shaft.	Extreme Diameter.	Extreme Thickness.	Diameter of Balls.	Number of Balls.	Revolutions per Minute. 10	50	100	150	200	300	400	500	600	700	800	900	1000	Load per Ball.	Extreme Safe Load per Ball without Permanent Set.	Crushing Load per Ball.
					Safe Working Load in lb.															
In.	In.	In.	In.																Tons.	Tons.
$\frac{3}{4}$	$1\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{16}$	11	2142	960	680	554	490	392	340	300	277	256	240	226	214	618	...	...
1	$2\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	13	3120	1400	985	805	697	570	494	442	402	373	349	329	312	757	$1\frac{1}{2}$	6
$1\frac{1}{4}$	$2\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{8}$	15	3350	1580	1060	865	750	612	530	475	434	400	375	354	335	707	...	...
$1\frac{1}{2}$	$2\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{16}$	16	5850	2620	1850	1470	1310	1070	925	830	756	700	655	618	585	1156	2	8
$1\frac{3}{4}$	$3\frac{1}{8}$	1	$\frac{1}{2}$	16	7460	3320	2360	1930	1670	1360	1180	1055	963	892	834	786	746	1475	3	12
2	$3\frac{3}{8}$	1	$\frac{1}{2}$	17	7580	3400	2400	1960	1700	1390	1200	1070	980	906	850	800	758	1411	...	...
$2\frac{1}{4}$	$3\frac{3}{4}$	$1\frac{1}{8}$	$\frac{9}{16}$	16	10400	4650	3290	2682	2325	1900	1645	1470	1345	1245	1160	1100	1040	2056	4	16
$2\frac{1}{2}$	$4\frac{1}{4}$	$1\frac{1}{4}$	$\frac{5}{8}$	17	16000	7150	5160	4130	3570	2920	2530	2250	2065	1910	1785	1720	1600	3034	5	20
$2\frac{3}{4}$	$4\frac{1}{2}$	$1\frac{1}{4}$	$\frac{5}{8}$	18	16600	7540	5260	4300	3720	3030	2630	2350	2140	1985	1855	1750	1660	2922	...	...
3	5	$1\frac{1}{2}$	$\frac{3}{4}$	17	25700	11500	8140	6550	5750	4700	4060	3640	3320	3070	2880	2710	2570	4790	$7\frac{1}{2}$	30
$3\frac{1}{4}$	$5\frac{3}{8}$	$1\frac{1}{2}$	$\frac{3}{4}$	18	26400	11800	8350	6800	5900	4830	4170	3740	3410	3160	2960	2780	2640	4640	...	...
$3\frac{1}{2}$	6	$1\frac{3}{4}$	$\frac{7}{8}$	17	37100	16600	11720	9500	8250	6760	5850	5250	4790	4430	4140	3910	3710	6894	9	35
$3\frac{3}{4}$	$6\frac{3}{8}$	$1\frac{3}{4}$	$\frac{7}{8}$	18	39282	17576	12410	10058	8725	7158	6194	5859	5072	4690	4384	4140	3925	6894	...	...
4	7	2	1	17	46500	24000	14700	11560	9300	7500	6570	6210	5360	4975	4660	4400	4160	8043	$10\frac{1}{2}$	41
$4\frac{1}{2}$	$7\frac{1}{2}$	2	1	18	49300	25400	15550	12450	9680	7930	6950	6490	5650	5250	4940	4660	4410	8043	$10\frac{1}{2}$	41
5	$8\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{1}{8}$	18	53760	32256	17920	13440	10752	8960	8064	7331	6451	5760	5561	5202	4887	8960	11	44

race from falling out when the whole bearing is lifted away.

The manufacture of ball bearings entails a very high class of workmanship, as already mentioned in the beginning, to ensure precision, and durability. Both balls and races must be hardened to enable them to retain their form; the balls are of cast steel, and can

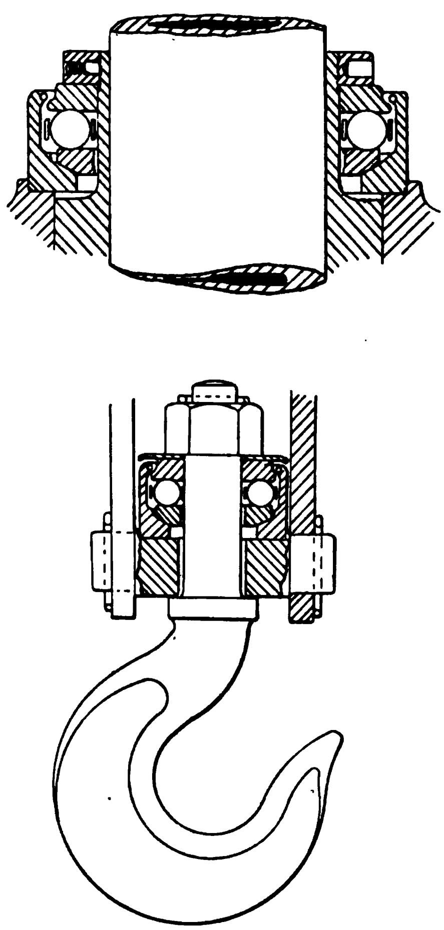


Fig. 58.—Thrust Bearings.
Upper Fig., thrust for drilling machine pillar.
Lower Fig., ditto for crane hook.

be now made within very close limits, both in regard to sphericity, and uniformity of size. Limits of from $\frac{1}{5000}$ to $\frac{1}{10000}$ inch are worked to.

The balls are prepared first either in the form of forgings, stamped from bar in dies, or are turned up from bar in automatic machines, or they are cut as short cylindrical pieces from bar, and then rolled into spheres, in any of which forms they are then ready for grinding. This is not done in a single stage, but roughing and finishing operations are essential. The grinding is usually done across the face of a wheel, to which the balls are presented in quantity, and passed across, rolling as they go, in a groove in the holder. This is repeated until the balls are reduced sufficiently in size to make their escape into a receptacle. After this preliminary roughing, hardening is done, very often in an automatic furnace, through which they pass, being heated meanwhile, and are then shot into a bath of oil. Tempering succeeds the hardening. The finish grinding is performed in other machines, which embody provision for automatically controlling the finished size of the balls. Polishing, and final inspection complete the process.

The manufacture of the races is a question of grinding in the concluding stages, after hardening, so that any inaccuracies introduced by this process are eliminated. It will be apparent therefore that the perfection of the ball bearing is due to the employment of grinding machinery, without which commercial production would not be feasible.

The table on page 65 gives particulars of bearings having balls ranging from $\frac{5}{16}$-in. to $1\frac{1}{8}$-in. diameter, with safe working loads at various speeds, from the practice of the Auto-Machinery Co, Ltd.

Ball Bolt.—A bolt having its head, and sometimes the nut of globular form, to fit in semispherical recesses, which allows of slight swaying or swivelling motion occurring. The bottom faces of nuts alone are frequently globular, to allow the screw or bolt to accommodate itself to varying angles, a familiar instance of which happens in compasses and calipers, and in various types of joints. *See* **Bolt.**

Ball Breaker.—A ball suspended from a crane, and used to break up pig iron and scrap with. The ball usually weighs from half a ton to a ton, and when hoisted to a suitable height, is let fall by the release of a lever catch, pulled by a cord.

Ball Cage.—The cage which confines the ball of a ball-cock in proximity to its seating.

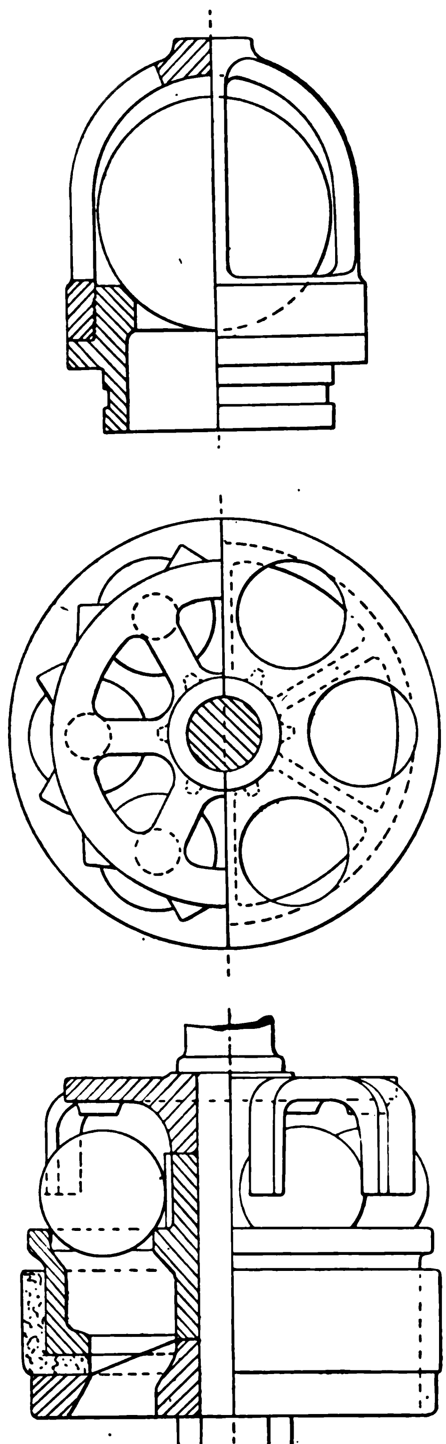


Fig. 59.—Examples of Ball Cages and Valves.

To permit of the insertion of the ball the cage is made in two parts screwed together, the cage proper above and the seating below. *See* Fig. 59.

Ball Casting.—Governor and other balls which have to be turned and polished free from specks are best cast in the manner shown in Fig. 60. The metal is run through a skimming chamber, having a riser coming up from it. The centrifugal action generated by the rotation of the metal in its passage through the chamber buoys the lighter matters to the top of the chamber, whence they collect in the riser.

Ball-Cock, or Ball-Valve.—This has two meanings. One that in which the cock or valve is closed by a floating hollow ball of copper at the end of a lever, as in cisterns.

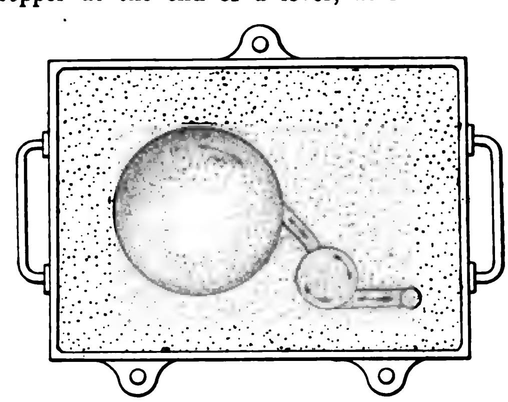


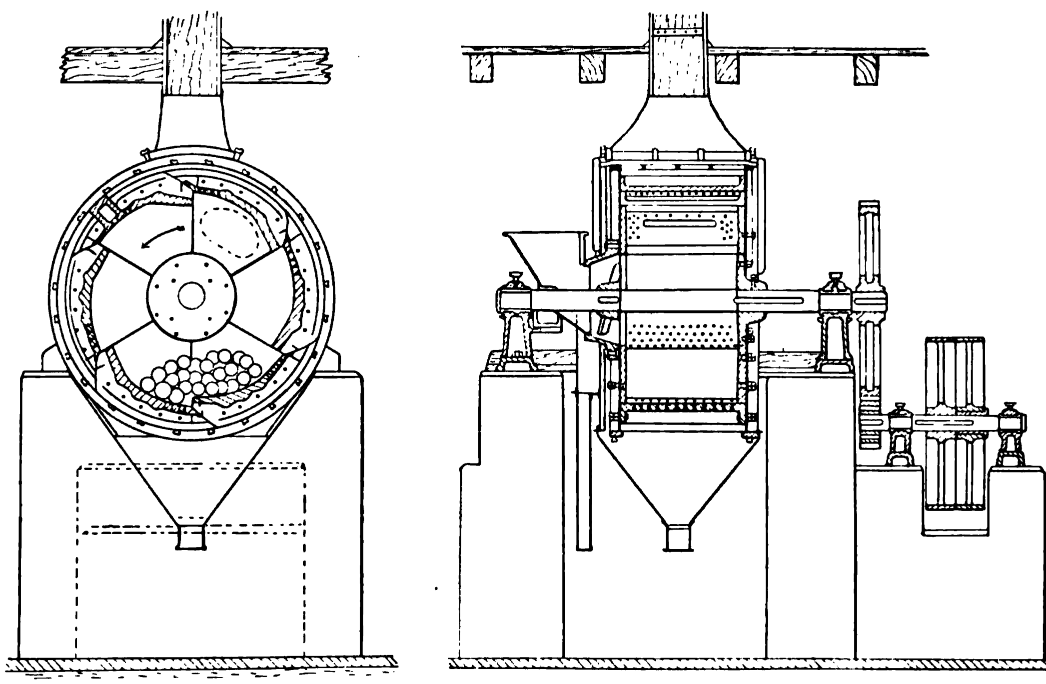
Fig. 60.—Ball Casting.

The other denotes the ball of brass or gun metal employed in check, and other valves in place of disc lift valves (*see* Fig. 59). The superiority of the ball over the latter lies in the constant change of position of the ball around its axis, by which equal wear is ensured.

A particular application of a ball-valve is embodied in some water-gauges. In these there is a ball in the lower portion below the gauge glass. In the event of the glass breaking, the outward rush of steam drives the ball up against a seating in the passage way, and shuts off the steam.

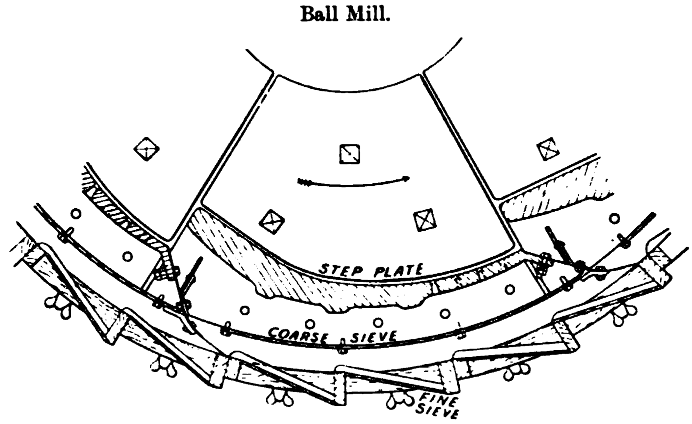
Ball Counterweight.—A weight made to grip the lower end of a crane chain, just above the hook, to overhaul the chain when it is not strained by a load.

iron pyrites, lead ore, lime, loam, litharge, moulding sand, ores of various kinds, sulphur. Some are mounted on a central axle and are belt driven, others of larger size revolve on rollers and are driven by a belt on a pinion shaft, which gears with a toothed ring encircling the barrel at the centre.



Ball Mill.

A recent patented ball mill by Fried. Krupp, Fig. 61, embodies the following leading features: — The drum is of the rotary type, which is revolved with its axle, by belt and gear wheels situated externally to the drum, the special features being within. The balls do not revolve on a regular cylindrical surface, but the drum is lined with separate grinding plates which form a series of steps, that in an exaggerated way may be said to resemble the backing off of cutters. The object of this is to throw the material down at the end of each step, and so lessen risk of the meshes of the sieves becoming choked. These step grinding plates are provided with holes or slots through which the ground material falls on a coarse cylindrical sieve surrounding, which keeps back the coarser grit, allowing the finer to pass through to a fine sieve outside that, and thence through a discharge funnel. The coarse grit that comes between the two sieves is conducted back to the interior of the mill.



Enlarged Detail.
Fig. 61.

The material for these mills is fed into a hopper at one side and thence by the blades of

... A smaller ... used by pat- ... makers, and other ... saw is particularly ... curved outlines are ... therefore, in pattern and ... considered more essen- ... machine. Band saws for ... advantageous, and are now ... that would have been considered ... few years ago. There is scarcely ... the thickness or kind of metal that these machines will saw. In fact for practical purposes the band saw can be made to divide anything that is not too bulky to be brought to it, and will do it cleanly, and with accuracy.

Band Wheel.—*See* **Belt Pulley.**

Banjo Frame.—A term sometimes applied to a **Bow Connecting Rod.**

Banker Engine.—A locomotive engine used for assisting trains up inclines.

Banking up.—The act of covering up a furnace fire with small coal for a period during which no steam is required, or but a small quantity. It is regularly done in large boilers for several months during the periods of cessation of work, as at night, and from Saturday to Monday, and when ships are in dock for a tide or two. The small coal is wetted and beaten down, the damper nearly closed, and the draught checked.

The term also denotes the enclosure of a forging in a smith's fire to be heated. The small coal is beaten round the forging to concentrate the heat, and the blast is then put on.

Bar.—This has several significations, as rolled bar of square or rectangular section, *see* **Bar Iron.** The term is often loosely applied to other sections, as round bars, angle bars, channel bars, &c. It denotes the cross bars or stays in moulding boxes, the bridge of metal which separates the ports of engine cylinders, the fire or grate bars of boiler furnaces, a crow bar, an equalising bar, a length of plain wood or metal, &c. Specimen bars for testing are termed test bars.

Barbed Wire.—Varies in character according to the number of wires, and distances apart of barbs. It is two-ply, or three, and four-barb. Ordinary wire has the barbs 6 inches apart, the "thick-set" has them 3 inches apart. The former has 560 yards per cwt., the latter 448 yards per cwt.

Barbette Gun.—A gun mounted to be fired over, instead of through its protecting enclosure. The movements of these guns are effected hydraulically or electrically.

Bar Clamp, or **Cramp.**—A clamp used by woodworkers, having the screw lug fixed solidly to a long bar, often extending to several feet in length, along which the loose head is slid. The latter is set up approximately on the bar at intervals of an inch or two by a pin in drilled holes, or by ratchet teeth, and minute adjustment for pressure is applied through a sliding head operated by the pinching screw.

Bare.—A term commonly used in the shops to denote a dimension slightly under size. It is the difference between a tight and a slack fit of the calipers. The modern practice of precise gauging with minute limits of tolerance is causing the term to be less used than formerly.

Bare Conductors.—*See* **Conductors.**

Barffing.—A process named after the inventor, Frederic S. Barff, by which iron and steel are protected with a rustless coating of magnetic or black oxide, Fe_3O_4, which is formed when iron is oxidised at a high temperature in air, oxygen, or steam. It thus substitutes chemical affinity for the mechanical adhesion of paint, forming the coating at the expense of the metal. Professor Barff used superheated steam. Subsequently George and A. S. Bower, father and son, employed air and carbonic acid. The process is therefore generally known as the Bower-Barff. Great results were anticipated from these methods, but they have not been fulfilled. The process is an excellent one for small articles, but it is too costly and unsatisfactory for large pieces, partly due to distortion, partly to reduction of strength, and an increase in the dimensions of the work.

The articles to be protected are placed in a muffle, or in a chamber of fire-brick, heated by solid fuel or producer gas to a temperature of about 1000° Fahr. Superheated steam is admitted, or air, the quantity being under control. The period of treatment varies with the dimensions of the articles, and the depth to which pro-

in Great Britain. Besides sleepers, it is employed for piles and dock work generally, for the timber work of many big cranes, for railway wagons, heavy and light carpentry, besides wood paving. Its employment for ships' masts is not of so great importance as formerly, having been largely supplanted by steel. The great forests of Southern Russia, and of Prussia, and those bordering on the White Sea district and Sweden supply different qualities of timber of quicker or slower growth, softer or harder, and more or less resinous, so that experts are able to judge by inspection of the locality of the growth of the timber.

Baluster. — A small pillar or column of an ornamental character, combining curves and mouldings. A range of these makes a balustrade, with or without a base and hand-rail. In engineering structures these are made in wrought and cast iron, chiefly the latter, because the material lends itself to cheap ornamentation. They occur on bridges, staircases, balconies, and elsewhere. In some cases the balustrade is cast in lengths, with base and hand-rail, in others the balusters are separate castings fitted into a base, and capped with the hand-rail. Little differences in ornament often make important differences in the economy and cost of moulding such work.

Banca Tin.—A very pure tin which is obtained from the island of Banca in the Dutch East Indies.

Band.—A belt.

Banding.—*See* below, also **Bonding.**

Banding Press.—A machine for tightening the copper bands around steel projectiles. The machine by the Vauxhall & West Hydraulic Engineering Co. Ltd. shown in Fig. 62 is used at Woolwich Arsenal, by Cammells', Vickers, and elsewhere. It consists of a series of rams to the inner ends of which the squeezing dies (not shown) are attached. These are operated simultaneously through the distributing pipe A which is arranged on top of the ring, so avoiding the necessity of having a pit under the machine for examination. The rams are pulled back by the powerful springs shown. The shell is suspended from a jib crane, using a special clip for the purpose, with the nose upwards, and is thus lowered and lifted readily.

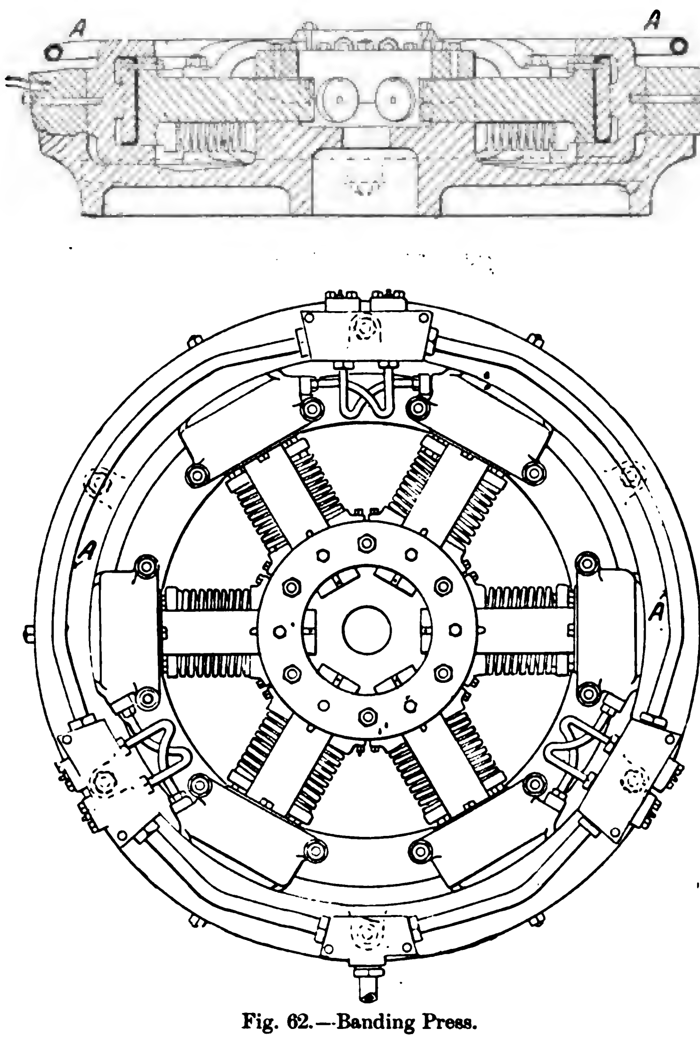


Fig. 62.—Banding Press.

Band Pulley.—*See* **Belt Pulley.**

Band Saw.—A band saw is an endless band of steel with teeth cut on one of its

edges. Motion is imparted to it in the same way as to a belt which runs round two or more pulleys. A machine with pulleys, or wheels, of suitable diameter, and at a proper distance apart is necessary in order to carry the saw. Band saws require careful and uniform setting and sharpening, and skilful fixing on

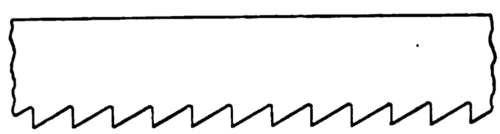


Fig. 63.—Band Saw Teeth.

the machine, which must be perfectly adapted for carrying them, otherwise they give trouble through frequent breakages. They are intended to run at a high speed, and the teeth, Fig. 63, are given more rake, or hook, than most of the saws for hand use.

The first obvious advantage of a band saw was that it would follow curved, or irregular outlines, instead of being limited to straight work as a circular saw is. But of late years it is in many cases preferred to the circular form for straight sawing. One important point in its favour is that it can be made much thinner than a circular saw, and so causes less waste in dust. Band saws are made in widths ranging from $\frac{1}{8}$ inch to 16 inches, according to the work for which they are required. For ordinary workshop purposes they are generally about $\frac{5}{8}$ inch wide. They work best in wood when running at a speed of about 4,000 feet per minute. The very large saws may be run at nearly twice that speed.

A peculiarity about band saws is that the front edge, the teeth, should be in a greater state of tension than the middle and back part of the blade. In wide saws the condition of the blade in this respect is very important. In these the back edge must be only in a slightly less state of tension than the front, and the middle part of the blade must be slack. The amount of slackness suitable for a given width is settled by the makers, but when saws have been in use, and broken, and twisted, and strained, it is necessary to test and re-hammer them, and for this purpose makers generally supply tension gauges. These are strips of steel with their edges finished to a certain sweep. When a saw blade is slack in the middle as it should be, the middle will drop if the blade is held horizontally and slightly strained by bending it in the direction of its length, as in Fig. 64. If a straight-edge is then tried across the blade it will be seen that it touches only at the back and front parts of the blade, and bridges across a concave middle part. The amount of this concavity should correspond with the curve of the tension gauge for that width of saw. The parts which require loosening are hammered to spread the metal. Instead of hammering, a machine called a band saw stretcher is sometimes used, and this is best for use in the shop by men who are not very skilful at saw hammering. In this machine the saw is passed between rollers under pressure, and so is reduced to a very uniform condition, and the required amount of tension thus imparted.

Band saws should also be examined occasionally for twists and lumps. These are reduced by hammering them down, care being taken not to hammer harder than necessary, or

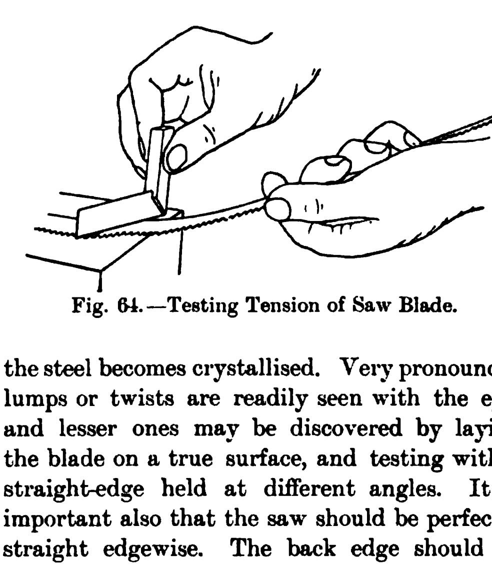


Fig. 64.—Testing Tension of Saw Blade.

the steel becomes crystallised. Very pronounced lumps or twists are readily seen with the eye, and lesser ones may be discovered by laying the blade on a true surface, and testing with a straight-edge held at different angles. It is important also that the saw should be perfectly straight edgewise. The back edge should be tested, and if it is hollow or rounding in places it is straightened by hammering, to spread the metal at hollow places. If the hollow part is at the back, the back and middle part in the vicinity are hammered. If the back is rounding

and the toothed side hollow, the toothed side and middle are hammered.

As a band saw contains a great number of teeth, and uniformity in them is essential, there are numerous machines for performing all the operations necessary to keep them in good cutting order. Machines have the double advantage of working more quickly and more accurately than is possible by hand. The necessary clearance is given to the saw either by setting, or by swaging the teeth. In the former case they are bent alternately slightly to each side. In the latter the teeth points are broadened by pressure in a suitable swage. These operations are not so frequently necessary as sharpening. Sharpening machines are provided either with an emery wheel or with a file, and in either case there is no risk of variations in angle as there is when a saw is filed by

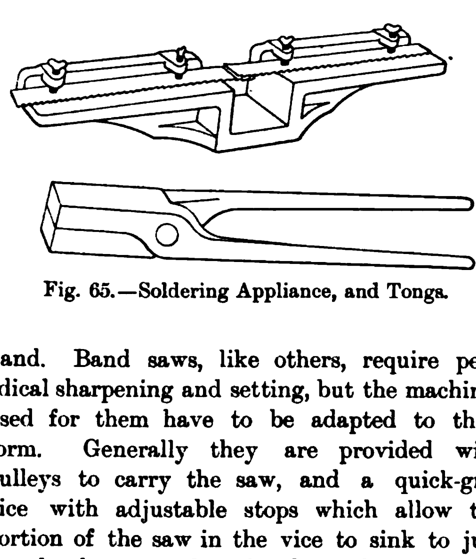


Fig. 65.—Soldering Appliance, and Tongs.

hand. Band saws, like others, require periodical sharpening and setting, but the machines used for them have to be adapted to their form. Generally they are provided with pulleys to carry the saw, and a quick-grip vice with adjustable stops which allow the portion of the saw in the vice to sink to just the depth required. *See* **Saw Sharpening Machines**.

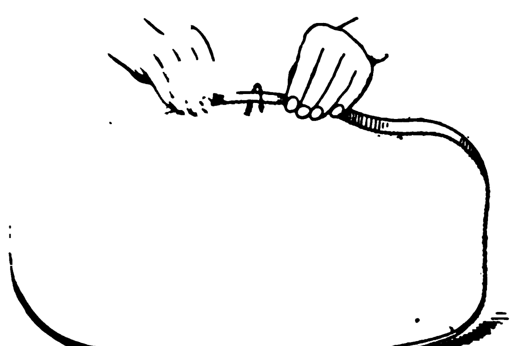
Special tools are required for repairing broken band saws. Chief among these is an appliance for holding the ends in position for soldering, Fig. 65. Its essentials are—a flat surface to lay the ends on, and a straight shoulder, or step at the back for the back edge of the saw to bear against, to ensure the ends being joined exactly in line with each other, also a number of set screws to clamp the saw down in position, and an opening at the place where the ends of the saw meet, so that tongs can be inserted during soldering.

The first step in preparing the broken ends of a saw for soldering is to file a scarfed joint. This extends generally about the distance of two teeth from each end. Starting from this distance the ends are bevelled to a feather edge at the extremity, so that when the two ends are fitted together the teeth match, and the overlapping portions are together no thicker than the rest of the saw. Machines are sometimes used for making this joint by means of a milling cutter, but on small saws it is a comparatively easy thing to do it by hand with a file. For a soldering medium either brass or silver solder is used. The latter is more expensive and its only advantage is that it melts at a lower heat. Brass may be used in sheet, or filings, or wire. The ends are clamped in position, special care being taken to see that the back of the saw is in line, and then a little powdered borax made into a paste with a few drops of water is applied to the faces of the joint. Then the brass or silver solder is inserted and heat and pressure applied. Generally thin iron wire is wound round the joined ends as a precaution against their getting out of position during soldering. Often the heating and clamping together of the joint is done by means of flat-jawed tongs, Fig. 65, applied red hot. Sometimes the jig in which the saw is held is fitted with a screw clamp and wedges which take the place of tongs, and sometimes the heating is done with a blow lamp. After the solder is set the joined part is trimmed down with a file to the same thickness as the rest of the saw.

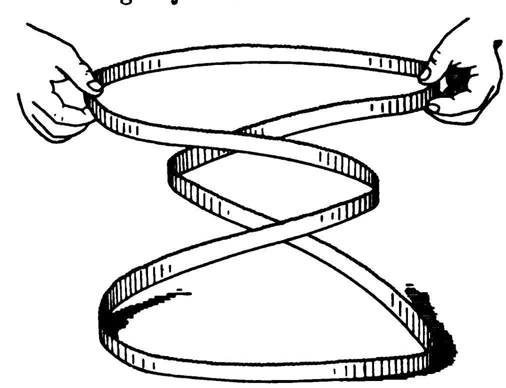
Band saws being peculiarly liable to fracture, sharp angles at the teeth bases should be avoided. A file should be used that will leave a considerable curve in the gullet. Vibration in running is bad for a band saw. Pressure against the guides should be avoided. Driving power should not be applied suddenly. The saw should not be forced or allowed to get very dull. The tensional strain put upon the saw should be only sufficient to prevent it from slipping on the wheels during a heavy cut.

When band saws are off the machine it is more convenient to keep them folded in coils than at their full length. When broken they

[illegible] unbroken saw [illegible] by a person [illegible] by twisting [illegible] divide it into [illegible] and these circles [illegible] each other and remain [illegible] untwisted again. Two com- [illegible] necessary to accomplish this [illegible] must remain in its original [illegible] When the twisting is finished the [illegible] the same way as at first, but [illegible] made in the blade which has [illegible] being formed.



The saw in position for making the first twist. Arrow shows the direction in which it is being twisted.



The folded saw raised to show how the coils lie.

Figs. 66.—Folding Band Saw.

The saw folded and tied.

Band Saw Machines.—The band saw is a development of the last century. In recent years it has attained a very high degree of efficiency and is more commonly used than any other kind of machine saw. To obtain satisfactory results the machine which carries it has to be very skilfully devised. If both are not just as they should be there is constant trouble through breakages of the saw. A band saw machine (Fig. 67) consists of pulleys or wheels for the saw to run on, a table on which the work can rest while being cut, and a suitable standard to provide bearings for the wheels, and usually also to attach the table, driving belt pulleys, saw guides, and other details to. Usually the saw runs on two wheels, but occasionally three are employed. Their centres must be adjustable to and from each other, and the saw must be strained considerably on them to prevent it from slipping. A certain amount of spring is required after the wheel centres have been adjusted to suit the saw. The rims must be covered with rubber to prevent injury to the saw teeth, and a very slight amount of crown is necessary to keep the saw in correct position on them. In addition to this one of the wheels should have a swivelling adjustment to further control the path of the saw and prevent it from running off the rims. The commonest type of band saw machine has two wheels, one above the other, for carrying the saw. The lower wheel is driven and the upper one is carried round by the saw in the same way as a belt carries movement from a driven pulley to the one it drives. Not to put more driving strain than can be avoided on the saw the upper wheel is made light, and should start as easily as possible. The frame or standard which supports the wheels and table is a hollow rigid casting. The table and wheels are of iron. Sometimes the wheels have wood rims, chiefly for lightness, and because the rubber can be more easily attached, but as absolute truth is essential in order that the saw may not be subjected to varying strains, wood cannot be considered equal to metal. The upper wheel has a vertical adjustment of six or more inches, the rise and fall being operated either by a hand wheel or by a lever. This per-

mits adjustment for saws of slightly different length and allows the saw to be slipped on loose and the requisite amount of tension imparted to it by raising the upper wheel. When a lever is generally considered best to raise and lower the upper wheel by means of a screw and hand wheel, and to employ a coil spring instead of a weighted lever to give the required resilience.

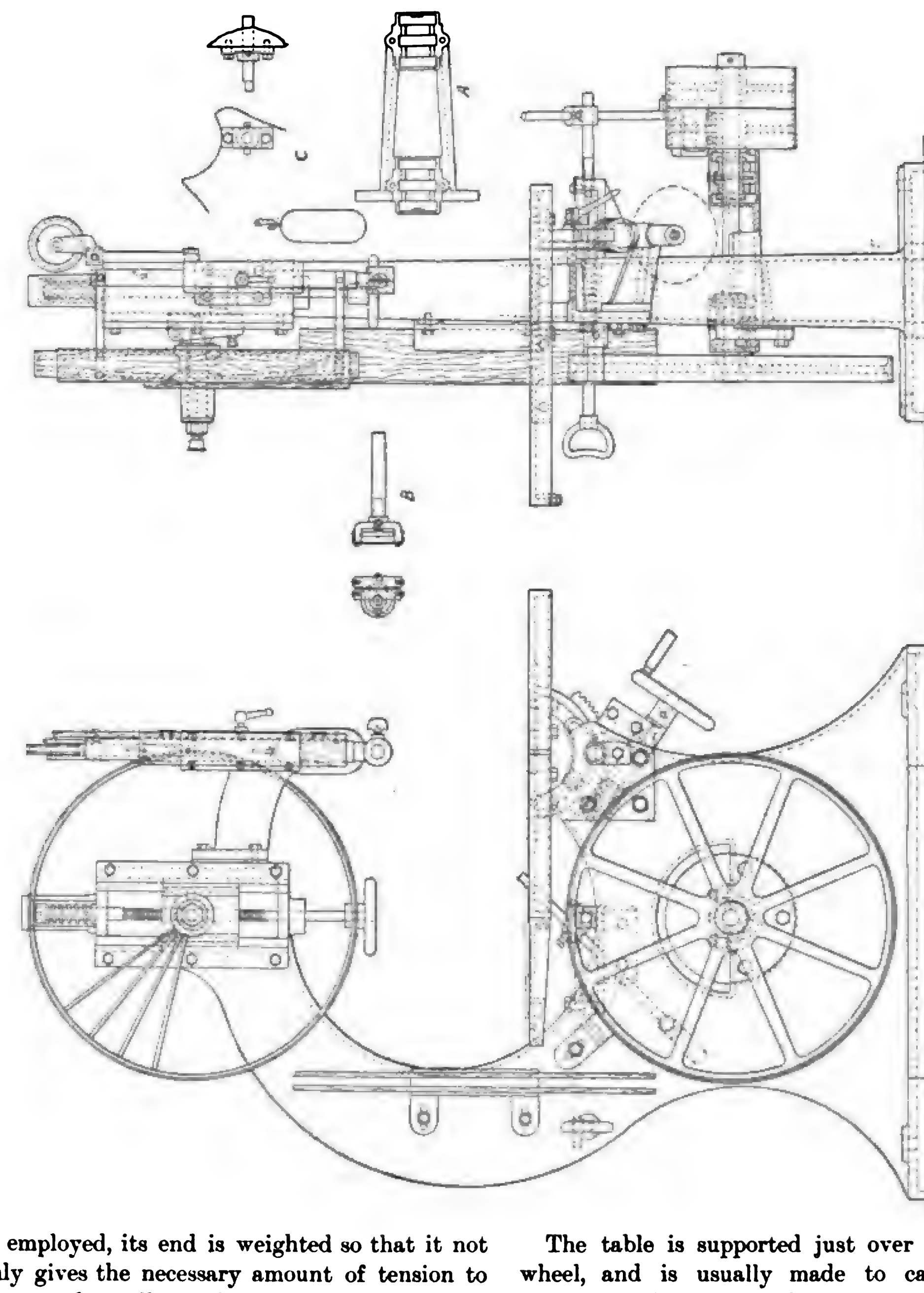


Fig. 67.—30-inch Band Sawing Machine. (J. Sagar & Co., Ltd.)
A. Plan of bottom bearing. *B*. Roller guide. *C*. Attachment for guide when fixed under table.

is employed, its end is weighted so that it not only gives the necessary amount of tension to the saw but allows the necessary amount of spring also. In the latest designs, however, it

The table is supported just over the lower wheel, and is usually made to cant. The saw passes down through a slot in the table, and an adjustable guide is provided for it

to run through immediately above the work it is cutting. This guide is provided with a revolving back which prevents the saw from being pushed back when the work is fed against it. The guide is also arranged to steady the saw laterally. It is made to rise and lower to suit the thickness of the material which is being cut. A removable fence to go on the table for use in the same way as a circular saw fence, is generally supplied. The lower wheel is frequently boxed in and the rising part of the saw enclosed by a guard. This is the type that has been found most suitable for the ordinary work in a pattern or cabinetmaker's or joiner's shop, and the general appearance of these machines cannot vary greatly.

Band saws vary in size according to the work they are intended for. Formerly their chief advantage was considered to be for sawing to curved outlines, and for straight heavy work, circular saws, or frame saws with reciprocating movement were used. These latter in a gang were for a long time considered the best possible means of sawing logs into planks. But of late years the band saw has been coming steadily into favour for all purposes, and other types are used correspondingly less. In the large machines for doing heavy work, appearance and details vary more than in the small machines. The wheels carrying the saw are still there, but they may be arranged horizontally instead of vertically, or they may be capable of variation so that the saw can be worked at angles between the horizontal and vertical positions. The table is no longer a plain flat surface on which the work is fed by hand, but is adapted for holding and feeding the wood forward to the saw. Sometimes the table travels, sometimes the wood is advanced by vertical or horizontal rollers on a stationary table. Roller feed can only be employed for wood that has already been reduced from the log and possesses straight faces for the rollers to work against. Saws fitted with rollers for the further reduction of planks are known as re-saws. Machines with travelling tables are used for the sawing of logs. The feed movement of the table is usually by rack and pinion. Suitable clips are provided for gripping the log. In vertical saws for heavy work the lower wheel is frequently sunk below the floor level so that the wood can travel on a low table on the floor. Vertical band saws of all classes are generally made with the descending part of the saw which does the cutting, to the right of the operator, and the rising side to the left. Occasionally the opposite hand is built, and sometimes double saws are employed, one right and the other left adjustable to and from each other. This enables the two descending blades to cut simultaneously at a given distance apart.

Band saws are also used to a considerable extent for cutting metal (*see* Fig. 68, and Figs. 69-71, Plate II.). They are handy for cutting plates, girders, angle irons, bars, tubes, sprues from small castings, &c. Saws used for this work require lubrication, and are run at a lower speed than those for wood. The rate of speed suitable depends on the metal which is to be sawn. Soft metals and alloys such as copper, brass, and wrought iron may be cut with a faster running saw than hard metals like steel and cast iron. They require sharpening about as frequently as wood-cutting saws. The tables of machines for sawing cold metal are provided with T slots for bolting work to the table, and the feeding may be done either automatically or by a hand wheel and screw. The rate of feed depends on the thickness of metal being sawn. In lighter classes of work it is not necessary to bolt to the table, and light metal sawing machines merely have a plain table, with or without mechanical means of feeding the work to the saw. Wrought iron and mild steel may be cut at the rate of about one square inch per minute; cast iron and steel much more slowly. The thickness makes a difference in the rate of cutting. As compared with this a wood-cutting band saw would sever wood perhaps 100 to 200 times faster.

As saws for metal run at a lower speed and require great power they are often driven by a pinion gearing into teeth on the rim of one of the wheels (*see* Fig. 68). The method of feeding also becomes an important matter, and in some cases the saw is fed to the work instead of the work to the saw. This may be accomplished in a vertical saw by mounting the entire machine on

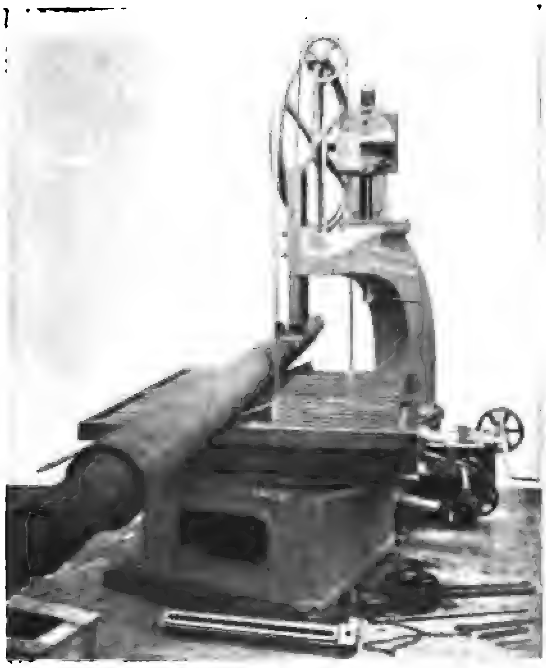


Fig. 69.—Band Sawing Machine for Metal. (Noble & Lund, Ltd.)

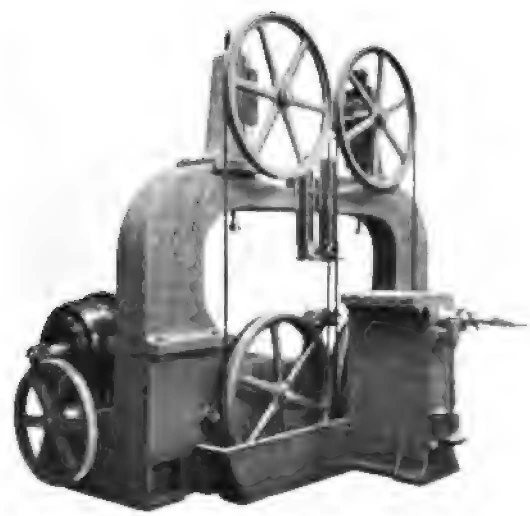


Fig. 70.—Double Band Sawing Machine for Metal. (Noble & Lund, Ltd.)

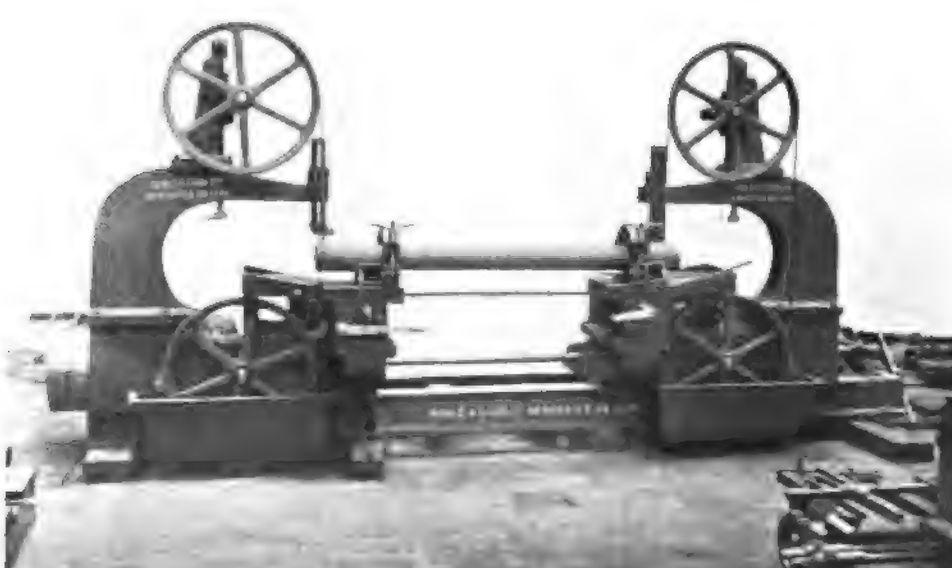


Fig. 71.—Band Sawing Machine, mounted on Long Bed. (Noble & Lund, Ltd.)

To face page 76.

slides so that it can travel past a fixed table. In a horizontal machine the teeth may work downwards, and the frame which carries the wheels move vertically between guides. For metal sawing the table is frequently divided entirely at the saw instead of being provided with a slot. One half may slide and the other be fixed, or both may be on slides, but capable of independent working.

Band Saw Work.—There is very little in the way of sawing that cannot be performed by a band saw. It may be used for the lightest and heaviest work, and for square, angular, or curved cutting. A band saw cuts rapidly, wastes little in sawdust, and can be used for any kind of work that can be brought to the machine, except the cutting of long grooves and rebates which only a circular saw can perform, and the cutting out of interior parts where a jig saw, or one used by hand are the only kind that will enter. No matter what class of work is performed in a shop, a band saw may be considered the most suitable if only one machine saw is employed there. A circular will do a great deal, costs less than a band saw, and is less likely to get out of order; but it is limited to cutting in straight lines, and one circular will not perform both ripping and cross-cutting as satisfactorily as a band saw will. As it cuts a much wider kerf than a band saw the consequent waste of material is considerable in mills where logs and planks are constantly being cut down by circulars. In another respect also the band saw is more economical. The less material there is removed the more rapid will be the advance of saw with a given amount of driving power.

Different classes of band saw are used. In mills, large saws are used for the heavy work of log cutting, and a slightly smaller and different

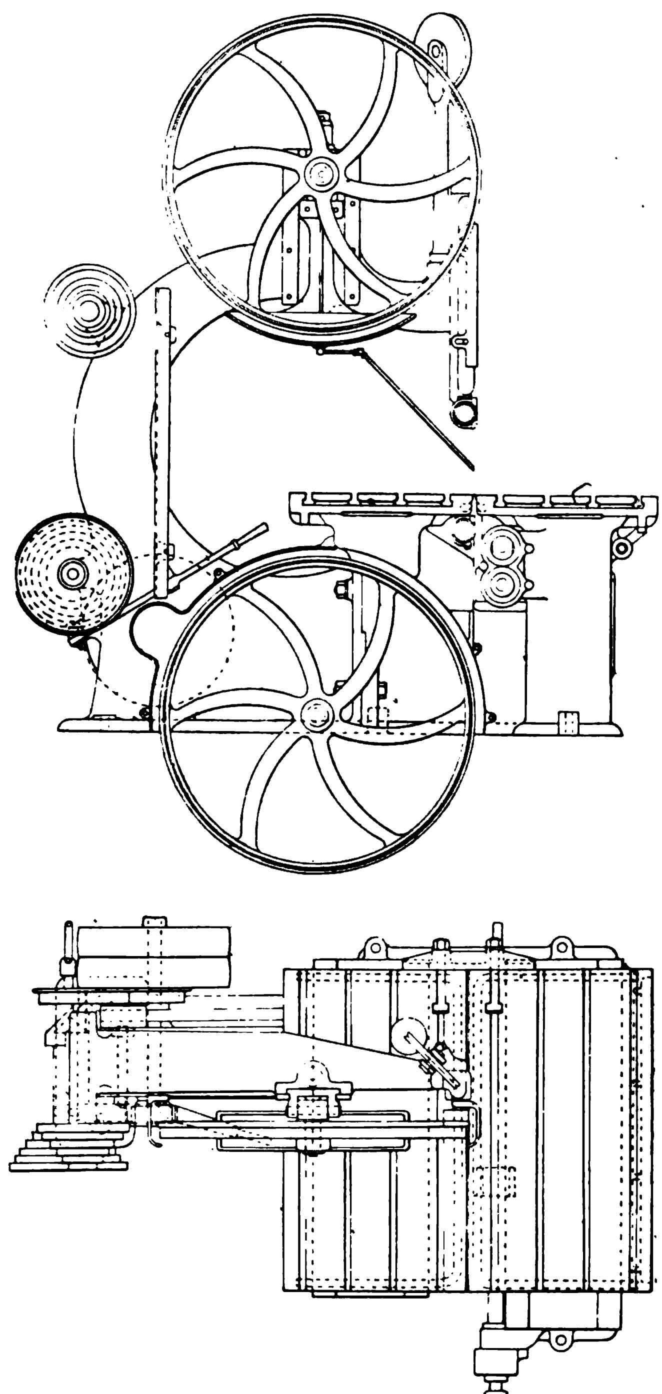


Fig. 68.—Band Sawing Machine for Metal. (B. & S. Massey.)

kind of machine for re-sawing. A smaller and simpler form of band saw is used by patternmakers, cabinet-makers, joiners, and other woodworkers. The band saw is particularly useful in shops where curved outlines are often being done, and therefore, in pattern and cabinet shops it may be considered more essential than any other machine. Band saws for metal are equally advantageous, and are now used for work that would have been considered impossible a few years ago. There is scarcely a limit to the thickness or kind of metal that these machines will saw. In fact for practical purposes the band saw can be made to divide anything that is not too bulky to be brought to it, and will do it cleanly, and with accuracy.

Band Wheel.—*See* **Belt Pulley.**

Banjo Frame.—A term sometimes applied to a **Bow Connecting Rod.**

Banker Engine.—A locomotive engine used for assisting trains up inclines.

Banking up.—The act of covering up a furnace fire with small coal for a period during which no steam is required, or but a small quantity. It is regularly done in large boilers for several months during the periods of cessation of work, as at night, and from Saturday to Monday, and when ships are in dock for a tide or two. The small coal is wetted and beaten down, the damper nearly closed, and the draught checked.

The term also denotes the enclosure of a forging in a smith's fire to be heated. The small coal is beaten round the forging to concentrate the heat, and the blast is then put on.

Bar.—This has several significations, as rolled bar of square or rectangular section, *see* **Bar Iron.** The term is often loosely applied to other sections, as round bars, angle bars, channel bars, &c. It denotes the cross bars or stays in moulding boxes, the bridge of metal which separates the ports of engine cylinders, the fire or grate bars of boiler furnaces, a crow bar, an equalising bar, a length of plain wood or metal, &c. Specimen bars for testing are termed test bars.

Barbed Wire.—Varies in character according to the number of wires, and distances apart of barbs. It is two-ply, or three, and four-barb. Ordinary wire has the barbs 6 inches apart, the "thick-set" has them 3 inches apart. The former has 560 yards per cwt., the latter 448 yards per cwt.

Barbette Gun.—A gun mounted to be fired over, instead of through its protecting enclosure. The movements of these guns are effected hydraulically or electrically.

Bar Clamp, or **Cramp.**—A clamp used by woodworkers, having the screw lug fixed solidly to a long bar, often extending to several feet in length, along which the loose head is slid. The latter is set up approximately on the bar at intervals of an inch or two by a pin in drilled holes, or by ratchet teeth, and minute adjustment for pressure is applied through a sliding head operated by the pinching screw.

Bare.—A term commonly used in the shops to denote a dimension slightly under size. It is the difference between a tight and a slack fit of the calipers. The modern practice of precise gauging with minute limits of tolerance is causing the term to be less used than formerly.

Bare Conductors.—*See* **Conductors.**

Barffing.—A process named after the inventor, Frederic S. Barff, by which iron and steel are protected with a rustless coating of magnetic or black oxide, Fe_3O_4, which is formed when iron is oxidised at a high temperature in air, oxygen, or steam. It thus substitutes chemical affinity for the mechanical adhesion of paint, forming the coating at the expense of the metal. Professor Barff used superheated steam. Subsequently George and A. S. Bower, father and son, employed air and carbonic acid. The process is therefore generally known as the Bower-Barff. Great results were anticipated from these methods, but they have not been fulfilled. The process is an excellent one for small articles, but it is too costly and unsatisfactory for large pieces, partly due to distortion, partly to reduction of strength, and an increase in the dimensions of the work.

The articles to be protected are placed in a muffle, or in a chamber of fire-brick, heated by solid fuel or producer gas to a temperature of about 1000° Fahr. Superheated steam is admitted, or air, the quantity being under control. The period of treatment varies with the dimensions of the articles, and the depth to which pro-

tection is desired. It may range from five hours to twenty.

Bar Iron.—Iron sections which are round, square, or flat (oblong in section). The term should properly be restricted to these, but others are often denoted thus; as angle bars, channel bars. Bar iron of good quality has a tensile strength of from 22 to 24 tons per square inch, with an elongation of 15 to 25 per cent. in 8 inches, and a reduction of area at the point of fracture of from 25 to 40 per cent. The bar iron of the smithy occurs in three grades, best, best best, and treble best, and the Yorkshire quality. Merchant bars are a low grade, not suitable for the ordinary work of the smithy, but which are used chiefly for piling, for producing the better qualities. Puddled bar is the first product of rolling, and is only employed for cutting up and piling for the production of merchant bar. Both rounds and squares are rolled from $\frac{1}{4}$ in. to 6 in.; squares advance by $\frac{1}{16}$ths in. up to $1\frac{1}{2}$ in.; from $1\frac{1}{2}$ in. to 4 in. by $\frac{1}{8}$ in.; from 4 in. to 5 in. by $\frac{1}{4}$ in.; from 5 in. to 6 in. by $\frac{1}{2}$ in. Rounds go by smaller measurements—$\frac{1}{64}$, $\frac{1}{32}$, $\frac{1}{8}$, and $\frac{1}{4}$ in. Flats are obtainable in a large range from $\frac{3}{8}$ in. $\times$ $\frac{1}{8}$ in. to $\frac{1}{4}$ in. up to 12 in. $\times$ $\frac{1}{2}$ in. by 2 in. That is, for the same width it is easy to roll different thicknesses by altering the distances between the axes of the rolls. In rolling bars, two sets of rolls are employed, roughing, and finishing, adjacent. In the first the grooves are angular, that is the angles are perpendicular and horizontal; in the second the grooves are parallel or flat. In what are termed the drawing passes, so named because during those the most rapid reduction takes place, the top and bottom angles of the angular grooves are generally flattened, so that fin formed in a preceding pass is squeezed down into the metal. Two-high and three-high rolls are both used for rolling bars, the former being the older type.

Barker's Mill.—A mechanical toy which illustrates the effect caused by a jet of water issuing under pressure from holes in opposite sides of a horizontal balanced tube. The tube takes the form of arms coming out on each side of a pivoted vertical tube, and near the bottom. Water being poured down the latter, comes out of the holes in the horizontal tubes, and so causes the mechanism to rotate. The effect is due to the unbalanced lateral pressure. It is equal to the weight of a column having the orifice for its base, and double the depth of the water for its height. It illustrates in a crude way the principle of the reaction turbine.

Bar Lathe.—This refers to the form of bed, an old type formerly much used for various lathes, comprising a solid bar of triangular cross-section. The style is still used for watchmakers' lathes of small size, including modifications as two flats, and a curve below, instead of truly triangular, and also approximately circular. The design suffers from lack of rigidity and stiffness, which though not perceptible in small lathes, doing delicate work, is a defect rendering the employment of the bar impossible in larger types. It has been supplanted to a considerable extent by the framed type of bed, having a hollow, approximately semicircular cross-section, and by the Pittler design, which is a stiffer section, though retaining the triangular shape, being to a certain extent truncated.

Bar Link.—A link in valve motion work, made solidly, as distinguished from a slot link. These links are single, or double, and the block slides upon, instead of within. They are cheaper to make than slot links.

Bar Magnet.—*See* **Magnet.**

Bar Mill.—A rolling mill for bars. *See* **Bar Iron.**

Barometer (from Gr. *baros*, a weight, and *metron*, a measure).—An instrument for measuring the weight of the atmosphere, and although of such great importance and immense value, its discovery dates back to less than 300 years ago. The Cistern Barometer consists of a 33-inch glass tube containing mercury and dipping into a reservoir of the same metal. Or the lower end may be bent round, the reservoir consisting of an expansion of this lower end. This is the type generally seen in weather glasses. The rise and fall of the mercury is indicated on a scale attached to the wooden case which contains the tube and cistern. There are, however, certain imperfections about the cistern type of barometer. It is obviously essential that the height of the column should be measured from the level of

the mercury in the cistern. But owing to the fluctuations in the tube, the level is continually changing in the cistern, so that readings on the fixed scale ought to be corrected so as to allow for this error. This difficulty may however be largely overcome by the use of a large cistern, for the effect of the fluctuations in the tube, spread over a larger surface is less noticeable. It is entirely avoided in Fortins' barometer, in which a boxwood cistern has a movable leathern bottom which can be raised or lowered at will by means of a screw. A fixed ivory pin indicates the zero level to which the mercury must be raised when an observation is made.

In the Siphon Barometer the tube is bent in the form of a siphon, and has the same bore throughout. The short branch here corresponds with the cistern, and the difference between the two levels in the two branches gives the correct height of the mercury. In some examples of this type of barometer the whole tube may be raised or lowered bodily by means of a screw at the bottom of the case, thus enabling the mercury level in the short branch to be adjusted to a fixed zero. The common wheel barometer or weather glass is a type of siphon barometer. In this instrument the tube, instead of terminating at the bottom in a cistern, is recurved so as to form an inverted siphon. As a rise in the mercury in the longer or closed limb is equivalent to a fall in the shorter limb, and *vice versa*, a float is placed on the surface of the mercury in the shorter limb, and is connected with a string passing over a pulley, and very nearly balanced by another weight on the other side. An index hand attached to the pulley moves over the surface of a dial plate, graduated so as to indicate the oscillations of the column. With an increase of pressure the mercury in the longer tube rises, and that in the short tube is depressed, together with the float, and this gives a small motion of revolution to the pulley and also to the index hand. A fall in the longer column causes the mercury with its float in the short limb to rise, and consequently moves the index hand in the contrary direction.

Since we use mercury in the thermometer to indicate changes in temperature we shall evidently find the temperature affecting the mercury in the barometer and so disturbing the readings. Here again then a correction must be made to ensure exact observations. Mercury expands $\frac{1}{9990}$ of its bulk for every degree Fahr., so that with equal atmospheric pressures in December and July the height of the mercury would be different owing to the expansion of the metal in the hotter month. The following calculation should therefore be performed to reduce any given observed height to that which it would be were the temperature of the mercury 32 degrees. Multiply the observed height by the number of degrees above or below 32 degrees; divide this result by 9990, and subtract the answer from, or add it to the observed height. The result gives the reduced height.

The readings of the barometer at different heights above sea level are useful as giving a measure of the loss of efficiency of air compressors, and pumps.

The altitude above sea level at which a compressor is to operate is an important point, the air being less dense at an elevation than at the sea level; hence, when working at an elevation the compressor takes in less air at each revolution than at a lower level, its capacity is diminished and there is a corresponding reduction in the power required to operate it.

The following table shows the efficiency, and loss in capacity of compressors working at different altitudes. It is computed for compressors delivering air at 60 pounds pressure per square inch :—

(Clayton Air Compressor Co.)

Altitude above Sea Level.	Barometer.	Efficiency of Compressor.	Loss.
Feet.	Inches.	Per Cent.	Per Cent.
0	30·	100·	0·
500	29·42	98·4	1·6
1,000	28·85	96·9	3·1
1,500	28·34	95·5	4·5
2,000	27·78	94·	6·
3,000	26·74	91·1	8·9
4,000	25·70	88·1	11·9
5,000	24·73	85·9	14·1
6,000	23·83	82·8	17·2
7,000	22·93	80·2	19·8
8,000	22·04	77·5	22·5
9,000	21·22	75·1	24·9
10,000	20·43	72·7	27·3

The next table shows how vacuum is reduced, and length of suction possible lessened in pumps.

TABLE OF BAROMETRIC PRESSURES, &c., FOR DIFFERENT ALTITUDES.

(MATHER & PLATT, LTD.)

Altitude above Sea Level.	Atmospheric Pressure at 60° Fahr.			Condenser Vacuum.	Length of Suction for High Lift Centrifugal Pumps.	
Feet.	Inches of Mercury.	Millimetres of Mercury.	Lb. per Square Inch.	Inches.	Theoretical Feet.	Practical Working Feet.
Sea Level	30·	762	14·6	27	33·9	16
500	29·4	747	14·46	26½	33·3	16
1,000	28·94	735	14·22	26	32·7	16
1,500	28·42	722	13·98	25½	32·1	16
2,000	27·91	709	13·72	25	31·5	15
2,500	27·41	696	13·48	24½	31·	15
3,000	26·92	684	13·23	24	30·4	15
3,500	26·43	671	13·	23½	29·9	14
4,000	25·96	659	12·76	23	29·3	14
4,500	25·5	648	12·52	22½	28·8	14
5,000	25·04	636	12·3	22	28·3	14
5,500	24·66	626	12·12	21½	27·8	13
6,000	24·15	613	11·87	21	27·3	13
6,500	23·72	602	11·66	20½	26·8	13
7,000	23·32	592	11·46	20	26·4	12
7,500	22·88	581	11·23	19½	25·9	12
8,000	22·47	571	11·03	19	25·4	12
8,500	22·07	561	10·84	18½	25·	12
9,000	21·67	550	10·64	18	24·5	11
10,000	20·9	531	10·27	17½	23·6	11
15,000	17·45	443	8·57	14	19·7	9
20,000	14·56	370	7·16	11	16·4	8

The last column is the practical total length of suction reckoned to the centre of the pump, including the vertical rise, the friction and the velocity of the water.

Barrage.—A French term, which in a general sense denotes the impounding of the waters of a stream for the purpose of regulating the supply. It is adopted for purposes of irrigation, and for ensuring a regular service for industrial, and domestic purposes. Its function is to store the excess of one season to supply the shortage of another season. It involves the construction of a dam or other device, with sluices, weirs, or other equivalents.

Barrages are of two kinds, the fixed, and the movable. The first term is applied to the dam form of structure which remains permanently, and through or around which the supply is regulated by movable sluices. The second denotes a form of structure in which the supply is regulated automatically or otherwise by movable beams, sometimes of timber, or by lifts. Many of these occur on the Seine.

The barrage of the Nile is the greatest work of this kind of modern times. Though so much has been done, the full scheme yet remains uncompleted. Egypt has possessed a system of irrigation from the time of King Menes, but the first barrage was begun in 1833, when Mehemet Ali commenced the barrages across the branches of the Nile north of Cairo.

In time of high flood, the Nile rises 33 ft. above its bed, in a mean flood 30 ft., and in a poor flood 23 ft. Egypt proper contains

[illegible] which [illegible] value of [illegible],000 at a [illegible]. About one- [illegible], because the [illegible] insufficient. To [illegible] reservoirs are required [illegible] 200,000 millions, [illegible] feet of water. This [illegible] increase in the rentable value [illegible],000 per annum.

[illegible] at the Assuan Cataract is [illegible] impounding 35 milliards of cubic [illegible] whenever it may be raised to a few [illegible] with the submergence of the temples [illegible] it will impound 70 milliards of cubic feet. Thus it will be seen that the famous Assuan dam is but a part of a wider scheme for the complete irrigation of Egypt. The additional 35 milliards will be worth £10,000,000, and this will not embrace the wider problems of the future, which are more far reaching, and were discussed at length in Sir William Garstin's Report (1904) on the Basin of the Upper Nile. They thus supply a middle link between the Delta barrages, begun in 1833, by Mehemet Ali across the Nile branches north of Cairo, and restored by Colonel Western in recent years, and the schemes of the future.

The Assiout barrage was commenced in 1898, and finished in 1902 at a cost, with subsidiary works of £869,546. It ensures a constant supply of water to Middle Egypt, and the Fayoum, doing for these districts what that at the apex of the Delta does for Lower Egypt. The width of the river at the site of the work was 900 metres (2,953 feet), the length of the dam is 833 metres (2,733 feet). The structure is an arched viaduct, resting on a broad solid masonry floor foundation. There are 110 piers, and the openings between them can be closed when necessary by iron sluice gates which slide in vertical iron grooves set in the sides of the piers. Two sluice gates, each 8 ft. 2 in. high are provided for each opening, and they are raised or lowered by overhead travelling winches running on rails the whole length of the barrage. A lock 52 ft. 6 in. wide is provided next the left bank for navigation.

The foundations are of masonry, forming a wide floor laid on the fine sand of the river bed, and sheet piling. Its bottom is 16 ft. 8 in. below the low summer level of the stream. The river level was about 25 ft. above the bottom of the floor at the commencement and termination of each season's work. Great difficulty was experienced here owing to the innumerable springs which burst out when the river bed was excavated; over a thousand large springs from 7 in. to 8 in. diameter being met with. At one time as many as twenty-eight centrifugal pumps of various sizes were at work excavating the water-saturated sand. The coal consumption for this work alone was 21,061 tons.

The river bed for a distance of 65 ft. 7 in. from the masonry floor on both the up and down stream side of the barrage is paved with rubble pitching. A roadway for traffic is carried over the barrage. A regulator is a subsidiary piece of work across the canal which conveys the waters from the Nile barrage to the lands to be irrigated.

The following quantities were used in the barrage and regulator. Rubble masonry and concrete 210,222 cubic yards, stone pitching 147,152 cubic yards, besides 642,370 cubic yards of temporary dams, rubble stone, sacks, and rope nets. The average number of men employed during the busiest season was about 7,500.

The dam at Assuan is a solid wall of granite masonry, pierced by 180 sluices, 140 being under sluices of 23 ft. by 6½ ft., and 40 upper sluices of 11½ ft. by 6½ ft. The total area of waterway is 24,000 square feet. The maximum flood of 475,000 cubic feet per second is discharged at a velocity of 20 ft. per second, and ordinary floods at a velocity of 16 ft. per second. Stoney self-balanced roller gates regulate the flow of water. Its total length is 2,750 ft., or rather more than half a mile. The piers and arches are founded on a platform of masonry 87 ft. wide, and 10 ft. thick, protected with cast-iron piling, with cemented joints, which goes down to a depth of 23 ft. below the upper surface of the floor into the sand bed of the river. Navigation is provided for by a ladder of four locks, each measuring 260 ft. by 32 ft. The reservoir can contain over 1,000,000,000 tons of water,

more than enough for a whole year's domestic consumption for the United Kingdom. This was completed in 1902.

Another barrage is that at Zifta on the Damietta branch of the Nile, midway between Cairo and the sea, opened in 1903. It is 408 yards long, comprising 50 arches, each 16½ ft. broad, and a lock 184 ft. long, by 40 ft. wide.

The 130 milliards of cubic feet of water supply still left unprovided for, when the Assuan dam shall have been raised to its full height, must come from the sources of the Nile. The question is one of money, for though the engineering difficulties are great, they can be overcome, and then the reclamation of the Soudan, with the Cape to Cairo railway would render all Egypt a fertile and valuable country.

A very deep barrage is that at Gileppe, Figs. 72 and 73, about 13 miles from Spa, built in 1867-1878. The hills surrounding the reservoir pour down vast quantities of a very pure soft water, which is impounded by the dam for the use of the town of Verviers, both for drinking purposes, and for the cloth factories. The dam carried across a narrow part of the valley of the Gileppe is 90 yards long, and 72 yards thick at the base, and 256 yards long, and 16 yards thick at the top. It contains 248,470 cubic metres. The height of the parapet is 154 feet. The dam is solid, that is, instead of being pierced with openings for the regulation of the supply, this is taken round it by two subterranean galleries in the form of a horseshoe. The reservoir contains 2,700 million gallons. Its area is 200 acres.

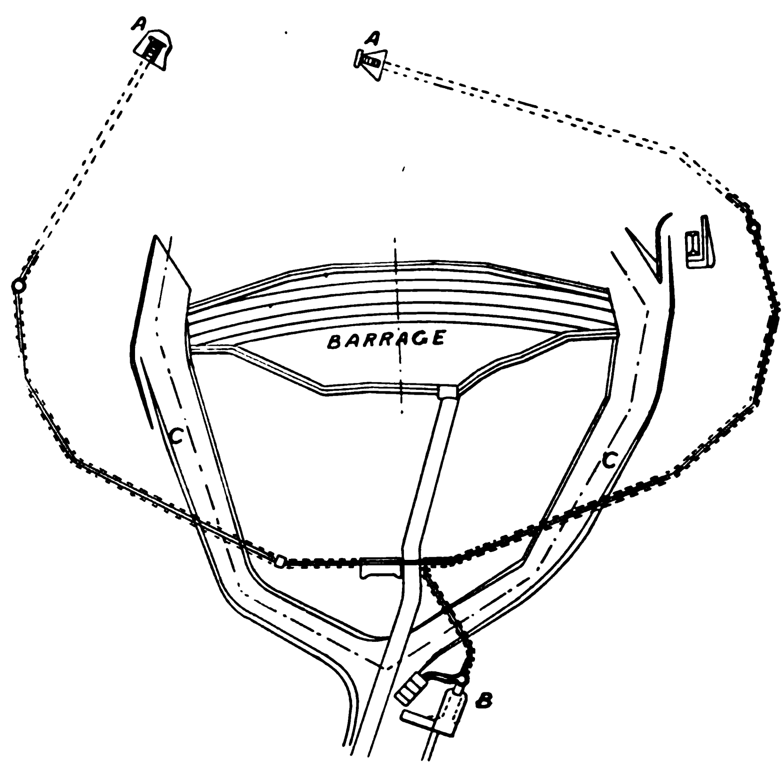


Fig. 72.—Plan of Gileppe Barrage.

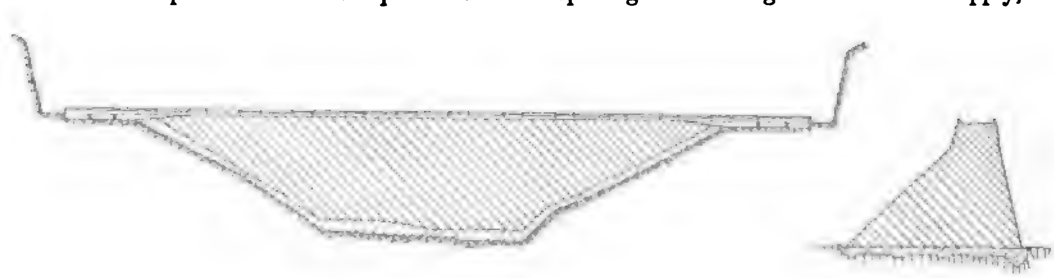


Fig. 73.—Longitudinal and Cross Sections of Gileppe Barrage.

The water taken away by the two subterranean galleries is filtered through a grating A at the upper end of each, and thence through a gallery to the sluices. Here a mass of masonry encloses two cast-iron pipes 34 inches diameter, each of which is closed at the lower end by a self-acting valve. After passing the working chamber the water arrives at another masonry dam, below

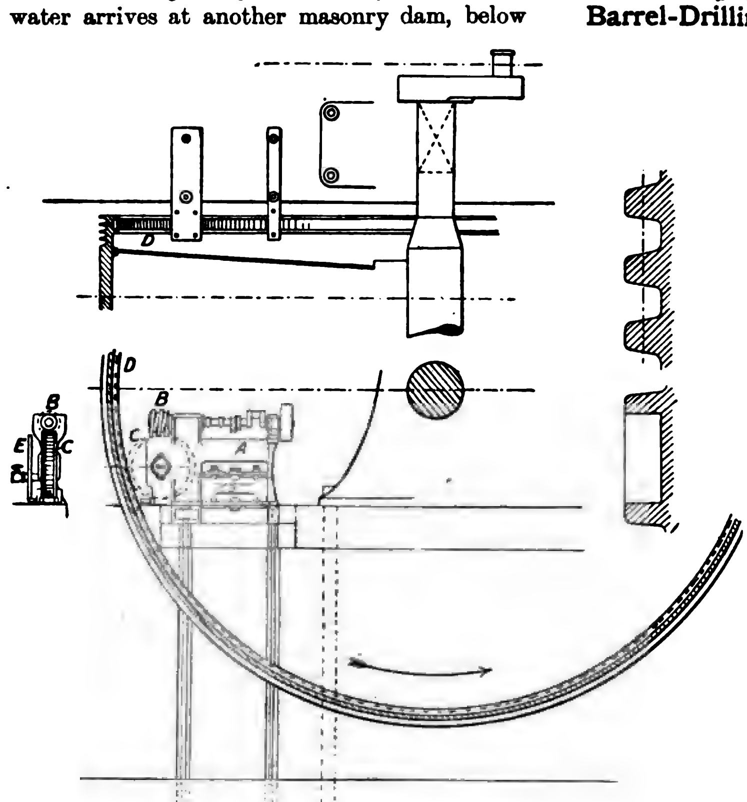


Fig. 74.—Barring Engine.

which is a safety sluice. Thence the water passes through a measuring apparatus B to the aqueduct. C, C, Fig. 72, are overflow channels. The cost of this work was 7,000,000 francs, or £280,000.

Barrel.—A term which has various significations. It is commonly applied to casks. It is a synonym for drum, as applied to cranes (*see* **Crane Drum**) whether of the plain, or the fusee type. It denotes the cylinder of a pump, a tumbling barrel for fettling castings, the tubular portion of a locomotive boiler as distinguished from the fire and smoke boxes, the shell of an internally fired boiler, as separate from the furnace tubes.

Barrel-Drilling Machine.—A special type of horizontal drilling machine, which though evolved primarily for gun-barrel work, is utilised extensively for other classes of deep drilling. Work of this kind can be done up to about 12 inch bore by 13 feet on these machines. The piece is revolved, and supported in bushed bearings, while the drill is fed in, a plentiful supply of lubricant being pumped along the drill body. The drill is attached to the end of a long bar or tube, the actual cutting portion consisting only of a small piece of steel. Guides are employed for steadying.

Lapping is another operation, which succeeds the drilling, being performed on somewhat similar machines. The barrel is slid to and fro while the lapping bar rotates in the bore.

Barrel Hoops.—The thin strips of steel which are rolled in strip mills for the hoops of casks, and of bales.

Barrel-Making Machines.—*See* **Cask-Making Machines.**

Barrel-Rifling Machine.—For rifling the barrels of guns, a special type of horizontal bed machine is employed. The barrel is gripped in an indexing chuck, which revolves for the correct number and spacing of grooves. The rifling bar is reciprocated back and forth, and is also given a twisting motion, which is variable, for different pitches. The bar is provided

with a special cutter, which is fed outwards automatically after each stroke, by means of a plunger, until the right depth of groove is reached. The average speed of cutting for ordinary steel is 30 feet per minute.

Barrel Stays.—Boiler stays for the barrels, as distinguished from those used in fire boxes.

Barring Engine.—A small engine fitted to nearly all mill engines, and large ones for electric light generation, which is rendered necessary by the great mass of these types of engines. The barring engine is used primarily for starting up, in place of "barring" round the flywheel by a pinch bar inserted in holes in the rim, the method commonly adopted in engines of medium dimensions. The object of the barring engine is more than this. Its function includes running the main engine for a short period until all parts are uniformly warmed up, moving it for the purpose of setting valves, for examining pistons and air pumps, &c., and for repairing, or putting on driving ropes and belts out of working hours.

The barring engine shown by Fig. 74 in its relation to the flywheel of the main engine is one by Hick, Hargreaves & Co., Ltd., of Bolton. It embodies an automatic disengagement which comes into play when the main engine begins to run quicker than the barring engine, as follows:—In Fig. 74 A is the barring engine (double cylinder in the example) the crank shaft of which drives the worm B. The wheel C indicated, in its "in," and "out of gear" positions by the dotted circles, has its teeth made as those of a worm wheel on one side—that driven by the worm—that is they are angled to suit the worm thread; and as a spur, square across, on the other—that which engages with the barring rack D. The in, and out position of the worm wheel is provided for by a slot (not shown) in the body casting, along which the wheel shaft may slide, and in its out of gear position can be held by two springs. A lever E furnishes the means by which the wheel is thrown. It holds a brake against the lower edge of the wheel, making it a fulcrum so that the rotating worm thrusts the wheel into gear with the barring rack. If the flywheel becomes the driver, the worm becomes the fulcrum, and the wheel slides back, and its shaft is retained there by the springs just now mentioned. When the barring engine is started there is no movement of the main engine until the lever is thrown in.

These engines are made to give either upward or downward thrust by simply placing the cylinders up or down, and altering the positions of the lubricators, and oil dish. The usual position is that shown in the figure, but this can be varied to suit different requirements.

For the majority of main engines the load when barring generally ranges from a fifth to a third the full power, but special cases, as those of some pumping engines, require more power. The following formula is given by Messrs Hick, Hargreaves & Co., Ltd., to obtain the average thrust in lb. required for a given main engine:—

$$\text{Average thrust in lb.}\left\{\frac{\text{IHP. at full load and speed} \times 10{,}509 \times \text{fraction of full load when barring}}{\text{Revs. per minute at full speed} \times \text{diameter of barring rack in feet.}}\right.$$

A liberal margin of power should be allowed, because the barring engine often has to be used out of work hours, when the boiler pressure is run low. These engines are designed for a working pressure of 100 lb. per square inch. Single cylinder engines as well as double are made.

Barring Rack.—The rack on the fly or rope wheel of a main engine in which the worm wheel of the barring engine engages. Pitches range from 3 in. to 5 in. The section used by Messrs Hick, Hargreaves & Co., Ltd., is shown in Fig. 74 full shrouded on each side.

Barrow Ladle, or Carriage Ladle.—A small foundry ladle mounted on a frame, having two front wheels, and two legs and handles behind. The shank turns in a socket, so that the ladle can be tilted to either side. Their capacity usually ranges from 2 to 4 cwt.

Barrow Pump.—A pump mounted for convenience on a hand barrow. Often termed a proving pump, and a California pump.

Bar Shears, or Bar Cropping Shears.—Shearing machines designed specially for cutting off bars of square, oblong, and round sections.

It is used primarily for cutting up puddled bars, and merchant iron for piling and reheating. But it is also employed in the smithy if a large volume of work is done. The type of machine is generally that of the ordinary shears, either single or double-ended, with the jaws set across, that is in the main plane of the machine, or at an angle so that in either case bars of any length can be passed through. In some recent machines for shop use there is a central set of shears for bars, and an outside set for narrow plates and steel pulley rims. In another type, provision for punching and shearing are combined in one machine. Fig. 75 illustrates one of the commoner designs of double-ended bar shearing machine. It is capable of shearing 2-inch square bars. The cam shaft A, 8 inches diameter, imparts a $2\frac{1}{2}$-inch stroke to the shears, and is driven through double gear from the crank shaft B, actuated by a single cylinder engine, 8-inch bore, by 10-inch stroke. Two fly wheels on the crank shaft steady the action by supplying a reserve of momentum.

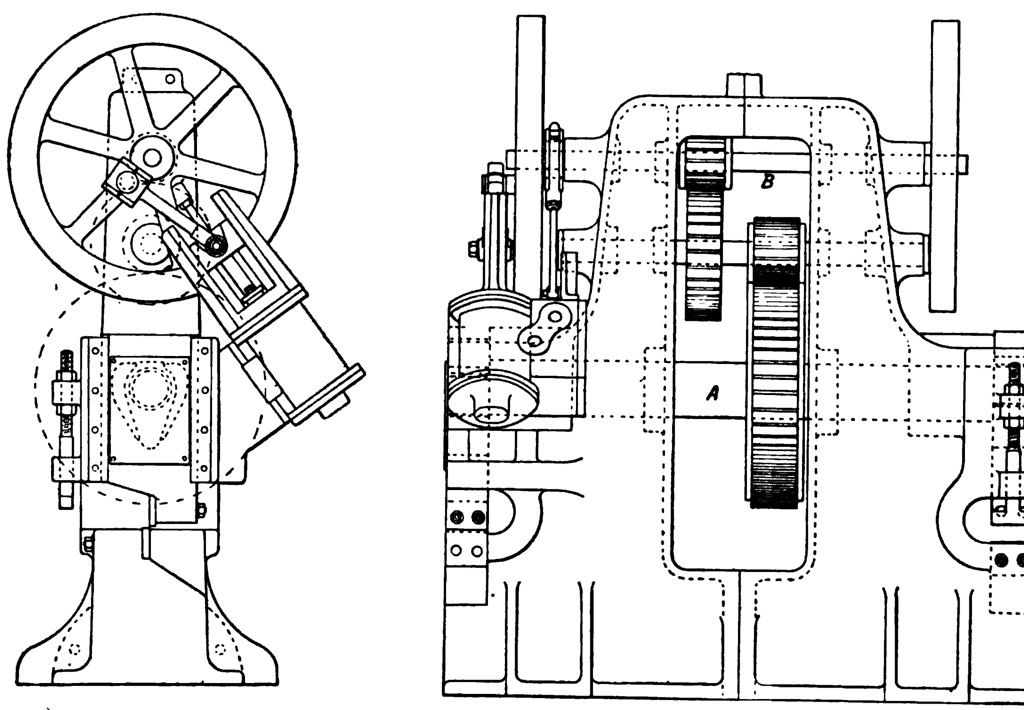


Fig. 75.—Double Bar Shearing Machine.

Bar Stays.—Boiler stays of solid round iron, or steel bar, with nutted ends, as distinguished from gusset stays, and tube stays.

Bar Steel.—This differs from bar iron in dimensions, being generally obtainable in larger sections than the former, and in its method of production. The piling necessary in iron is not adopted in steel, but the process is one of rolling only—termed "cogging"—from ingot to billet, then from billet to bar, with or without reheating. Improvements have been made in this work, as in other departments of steel manufacture. One of the most important is the **Continuous Mill** used for rolling bars and strips from billets, which is highly economical both of time, and crop ends.

Bascule Bridge.—A form of drawbridge, or opening bridge, the leaf or leaves of which turn on a horizontal axis, so opening or closing the passage, or water way for traffic over the bridge. In this country the best example is the Tower Bridge.

The bascule bridge must be provided with some form of counterpoise, or its equivalent, otherwise the power required for operating

the bridge will be excessive. It must also have a suitable recess to receive the counterpoise or tail, when lifted into the vertical position. There are alternatives, where the presence of the tail would be objectionable. There is also a method in which the balancing is rendered variable in amount, to maintain the bridge in approximate equilibrium in all positions, which cannot be done with fixed weights, unless the pivot passes through the centre of gravity of the bascule. Considerations of space available determine the length of counterbalance to the opening bridge.

The views, Figs. 76 and 77, show the counterbalancing arrangements of the Tower Bridge. Each bascule or leaf is hinged on a pivot shaft, Fig. 77, which measures 21 in. in diameter, by 48 ft. long. The bascule is built up of four girders 13 ft. 6 in. apart, braced together, and weighing in all about 1,200 tons. Each measures 113 ft. 3 in. in length from the pivot to the end, and the short arm is 49 ft. 6 in., a total of 162 ft. 9 in. It is 50 ft. wide.

The pivot has its bearings on live rollers, and the counterbalance is nicely adjusted so that comparatively little power is required to lift the bascules. The space available for counterbalance is small, hence the ballast is mostly composed of lead, 300 tons of which are used in each tail, besides 130 tons of cast iron. The pivot passes through the centre of gravity of the bascule, so that the balancing is equal in all positions.

The leaf is moved by gearing. A quadrant rack with steel teeth is attached to each of the lower portions of the outside girders, and is operated by two pinions. The racks are of cast steel, Fig. 78, each being a segment of a circle, with a pitch line measuring 42 ft. in radius. They are each about 6 ft. long and $15\frac{5}{8}$ in. wide, eleven segments in all, and fixed side by side. The pinions have thirteen teeth and are of $24\frac{1}{2}$ in. pitch diameter. These are operated by hydraulic pressure, for which, with other purposes, there is a generating plant, comprising two steam pumping engines, each of 360 horse power, eight hydraulic engines, and six accumulators.

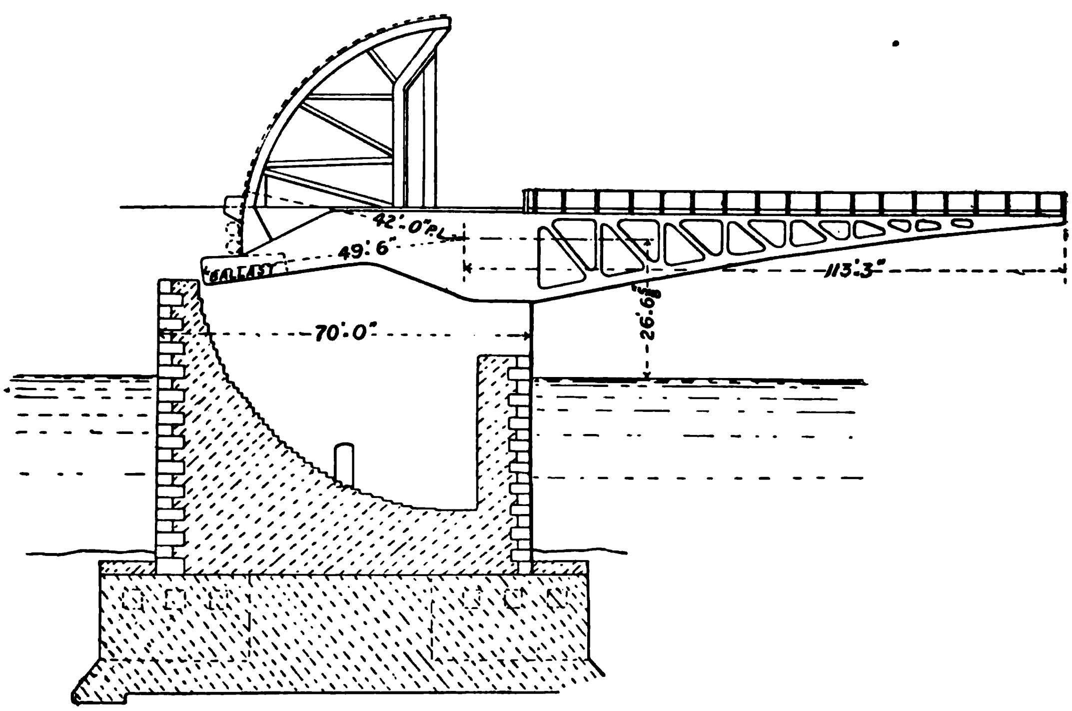


Fig. 76.—Bascule of Tower Bridge.

Each of the pumping engines has four steam cylinders of 38-in. stroke, two of which—high

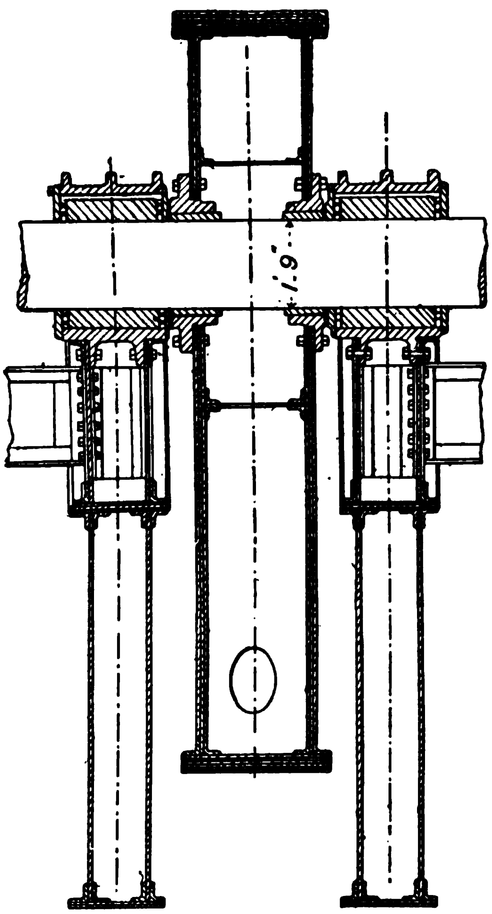


Fig. 77.—Section through Bascule and Pivot of Tower Bridge.

pressure—are of 19-in. bore, and two for low pressure of 37-in. bore. Each of the two hydraulic pumps connected to each engine has a plunger 7¾ in. diameter, with 38-in. stroke. There are two separate hydraulic engines at each end of the pier, each with three cylinders, the diameters of the pistons being 7½ in. and 8½ in. respectively, with 12-in. stroke. They can be used separately or in combination, the latter being necessary when the wind pressure is considerable. Additional power is gained by compound gearing.

In a bascule bridge in Van Buren Street, Chicago, Fig. 79, the leaves have quadrant girders attached to the bottom flange of the rear girders of the tail. The quadrant having a radius of 15 feet rests in a recess in its abutment. The movements of the levers are operated electrically through a train of gearing with automatic brakes, which would act if from any cause the current were cut off during the raising or lowering of the bridge.

The operating mechanism is rather complicated. It comprises a series of levers and cams, which being set in motion by the train of gearing unlocks the leaves at the centre, releases a stirrup that supports the rear end of the leaves, actuates a long rack within a strut, and so pulls the leaves backward and upward, causing the quadrants to roll on their paths attached to the abutments. The leaves of this bridge measure 57 ft. 6 in. long on the bridge proper, and 25 ft. 6. in. on the tail end.

Base.—Has various significations, the principal as regards the workshop, being a level surface on which work is built up, or from which it is marked out. In the first case it might take the form of blocking, in the second it is the marking-off table. In chemistry the base is the metallic or other substance from which salts are produced.

Base Circle.—The pitch circle in toothed gearing on which a generating circle is rolled to produce a cycloidal curve. In single curve gears it is the circle from which the curve is produced by the unwinding of a cord. This last does not coincide with the pitch line, but approaches nearly to the root of the tooth.

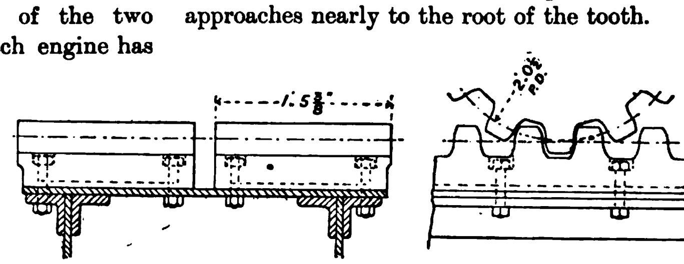


Fig. 78.—Gears of Tower Bridge.

Base Plate.—*See* **Bedplate.**

Basic Process.—*See* **Bessemer Process, Open Hearth Process.**

Basic Slag.—*See* **Bessemer Process.**

Basil.—The ground bevelled edge of a cutting tool. Some tools as chisels, adzes, plane irons, &c., have one basil only, others as axes, chipping chisels, turning chisels, &c., have two.

Basin.—*See* **Pouring Basin.**

Basin Irrigation.—A system of natural irrigation, so termed to distinguish it from that effected by **Barrage.** It is obtained by constructing large basins confined by dams to receive the turbid flood waters of rivers which have a rapid rise, and short season of flood. Mr Willcocks says that any country which possesses rivers and streams whose waters are in flood for six weeks per annum can adopt basin irrigation with more or less profit. Also that this system alone allows of the thorough development of countries whose streams have short and turbid floods.

The finest example of this kind is the Nile system, others are the storage tanks of Madras, and the basins of Bundelkund, where the water irrigates the crops on the down stream sides of basins for one season, and allows of the basins being cultivated in the next season.

The ancient system of Egypt was basin irrigation. A series of basins or compartments was constructed in the time of Menes by the reclamation of the left bank of the Nile by means of dykes, into which the waters of the stream were led. Afterwards the right bank was reclaimed by the Pharaohs of the twelfth dynasty. This scheme included the conversion of the Fayoum depression into Lake Moeris, which became a regulating basin. The flood waters were led into it during their height, and returned to the river when the inundation was over. As the Nile widened and deepened, Lake Moeris was reclaimed. The basin irrigation scheme holds the flood waters of the Nile for about forty-five days over the entire valley. The average depth is 4 feet, during which period the subsoil becomes saturated.

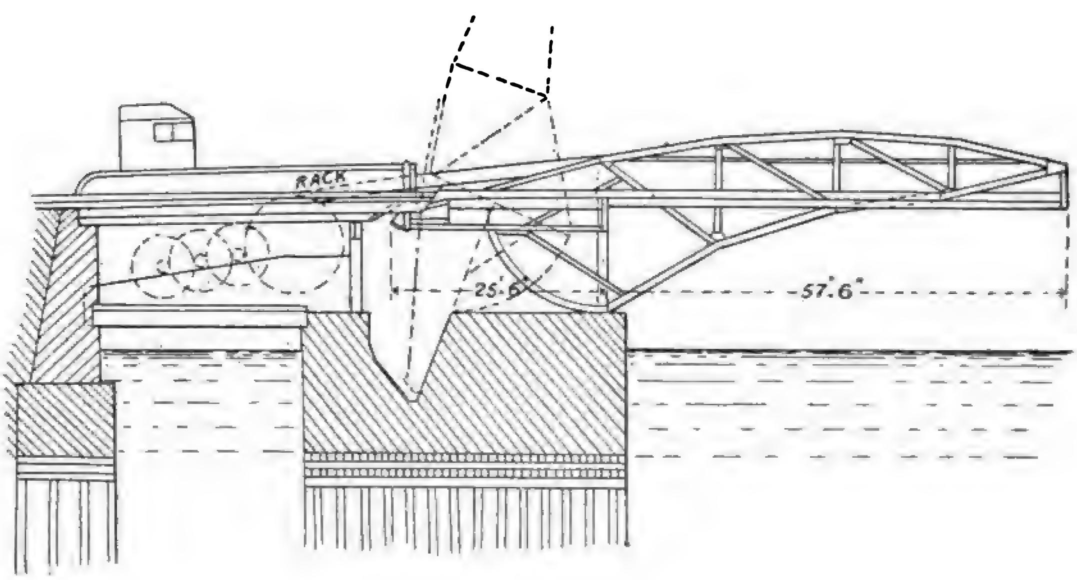


Fig. 79.—Bascule Bridge, Van Buren Street, Chicago.

This system is conducted through canals. The basins have an average area of 7,000 acres, but where the valley is narrow they only average 2,000 acres each, and where it is wide, 20,000 acres. Each canal supplies seven or eight basins, and there are regulators at the heads of the canals. The average width of the canals is 30 feet, some however are much wider than this. They discharge in an average year 1 cubic foot of water per second per 20 acres, and forty-five days suffice for a perfect irrigation.

In perennial irrigation produced by Barrage,

the mercury in the cistern. But owing to the fluctuations in the tube, the level is continually changing in the cistern, so that readings on the fixed scale ought to be corrected so as to allow for this error. This difficulty may however be largely overcome by the use of a large cistern, for the effect of the fluctuations in the tube, spread over a larger surface is less noticeable. It is entirely avoided in Fortins' barometer, in which a boxwood cistern has a movable leathern bottom which can be raised or lowered at will by means of a screw. A fixed ivory pin indicates the zero level to which the mercury must be raised when an observation is made.

In the Siphon Barometer the tube is bent in the form of a siphon, and has the same bore throughout. The short branch here corresponds with the cistern, and the difference between the two levels in the two branches gives the correct height of the mercury. In some examples of this type of barometer the whole tube may be raised or lowered bodily by means of a screw at the bottom of the case, thus enabling the mercury level in the short branch to be adjusted to a fixed zero. The common wheel barometer or weather glass is a type of siphon barometer. In this instrument the tube, instead of terminating at the bottom in a cistern, is recurved so as to form an inverted siphon. As a rise in the mercury in the longer or closed limb is equivalent to a fall in the shorter limb, and *vice versa*, a float is placed on the surface of the mercury in the shorter limb, and is connected with a string passing over a pulley, and very nearly balanced by another weight on the other side. An index hand attached to the pulley moves over the surface of a dial plate, graduated so as to indicate the oscillations of the column. With an increase of pressure the mercury in the longer tube rises, and that in the short tube is depressed, together with the float, and this gives a small motion of revolution to the pulley and also to the index hand. A fall in the longer column causes the mercury with its float in the short limb to rise, and consequently moves the index hand in the contrary direction.

Since we use mercury in the thermometer to indicate changes in temperature we shall evidently find the temperature affecting the mercury in the barometer and so disturbing the readings. Here again then a correction must be made to ensure exact observations. Mercury expands $\frac{1}{9990}$ of its bulk for every degree Fahr., so that with equal atmospheric pressures in December and July the height of the mercury would be different owing to the expansion of the metal in the hotter month. The following calculation should therefore be performed to reduce any given observed height to that which it would be were the temperature of the mercury 32 degrees. Multiply the observed height by the number of degrees above or below 32 degrees; divide this result by 9990, and subtract the answer from, or add it to the observed height. The result gives the reduced height.

The readings of the barometer at different heights above sea level are useful as giving a measure of the loss of efficiency of air compressors, and pumps.

The altitude above sea level at which a compressor is to operate is an important point, the air being less dense at an elevation than at the sea level; hence, when working at an elevation the compressor takes in less air at each revolution than at a lower level, its capacity is diminished and there is a corresponding reduction in the power required to operate it.

The following table shows the efficiency, and loss in capacity of compressors working at different altitudes. It is computed for compressors delivering air at 60 pounds pressure per square inch:—

(Clayton Air Compressor Co.)

Altitude above Sea Level.	Barometer.	Efficiency of Compressor.	Loss.
Feet.	Inches.	Per Cent.	Per Cent.
0	30·	100·	0·
500	29·42	98·4	1·6
1,000	28·85	96·9	3·1
1,500	28·34	95·5	4·5
2,000	27·78	94·	6·
3,000	26·74	91·1	8·9
4,000	25·70	88·1	11·9
5,000	24·73	85·9	14·1
6,000	23·83	82·8	17·2
7,000	22·93	80·2	19·8
8,000	22·04	77·5	22·5
9,000	21·22	75·1	24·9
10,000	20·43	72·7	27·3

The next table shows how vacuum is reduced, and length of suction possible lessened in pumps.

TABLE OF BAROMETRIC PRESSURES, &c., FOR DIFFERENT ALTITUDES.

(MATHER & PLATT, LTD.)

Altitude above Sea Level.	Atmospheric Pressure at 60° Fahr.			Condenser Vacuum.	Length of Suction for High Lift Centrifugal Pumps.	
Feet.	Inches of Mercury.	Millimetres of Mercury.	Lb. per Square Inch.	Inches.	Theoretical Feet.	Practical Working Feet.
Sea Level	30·	762	14·6	27	33·9	16
500	29·4	747	14·46	26½	33·3	16
1,000	28·94	735	14·22	26	32·7	16
1,500	28·42	722	13·98	25½	32·1	16
2,000	27·91	709	13·72	25	31·5	15
2,500	27·41	696	13·48	24½	31·	15
3,000	26·92	684	13·23	24	30·4	15
3,500	26·43	671	13·	23½	29·9	14
4,000	25·96	659	12·76	23	29·3	14
4,500	25·5	648	12·52	22½	28·8	14
5,000	25·04	636	12·3	22	28·3	14
5,500	24·66	626	12·12	21½	27·8	13
6,000	24·15	613	11·87	21	27·3	13
6,500	23·72	602	11·66	20½	26·8	13
7,000	23·32	592	11·46	20	26·4	12
7,500	22·88	581	11·23	19½	25·9	12
8,000	22·47	571	11·03	19	25·4	12
8,500	22·07	561	10·84	18½	25·	12
9,000	21·67	550	10·64	18	24·5	11
10,000	20·9	531	10·27	17½	23·6	11
15,000	17·45	443	8·57	14	19·7	9
20,000	14·56	370	7·16	11	16·4	8

The last column is the practical total length of suction reckoned to the centre of the pump, including the vertical rise, the friction and the velocity of the water.

Barrage.—A French term, which in a general sense denotes the impounding of the waters of a stream for the purpose of regulating the supply. It is adopted for purposes of irrigation, and for ensuring a regular service for industrial, and domestic purposes. Its function is to store the excess of one season to supply the shortage of another season. It involves the construction of a dam or other device, with sluices, weirs, or other equivalents.

Barrages are of two kinds, the fixed, and the movable. The first term is applied to the dam form of structure which remains permanently, and through or around which the supply is regulated by movable sluices. The second denotes a form of structure in which the supply is regulated automatically or otherwise by movable beams, sometimes of timber, or by lifts. Many of these occur on the Seine.

The barrage of the Nile is the greatest work of this kind of modern times. Though so much has been done, the full scheme yet remains uncompleted. Egypt has possessed a system of irrigation from the time of King Menes, but the first barrage was begun in 1833, when Mehemet Ali commenced the barrages across the branches of the Nile north of Cairo.

In time of high flood, the Nile rises 33 ft. above its bed, in a mean flood 30 ft., and in a poor flood 23 ft. Egypt proper contains

6,000,000 acres of cultivable land, of which 4,000,000 acres are rented at a mean value of £5 per acre per annum, and 2,000,000 at a mean rental of £1 per annum. About one-third of the country is undeveloped, because the summer supply of the Nile is insufficient. To develop Egypt to the full, reservoirs are required capable of supplying annually 200,000 millions, or 200 milliards of cubic feet of water. This would mean an increase in the rentable value of Egypt of £6,000,000 per annum.

The great dam at the Assuan Cataract is capable of impounding 35 milliards of cubic feet. But whenever it may be raised to a few feet higher (with the submergence of the temples at Philae) it will impound 70 milliards of cubic feet. Thus it will be seen that the famous Assuan dam is but a part of a wider scheme for the complete irrigation of Egypt. The additional 35 milliards will be worth £10,000,000, and this will not embrace the wider problems of the future, which are more far reaching, and were discussed at length in Sir William Garstin's Report (1904) on the Basin of the Upper Nile. They thus supply a middle link between the Delta barrages, begun in 1833, by Mehemet Ali across the Nile branches north of Cairo, and restored by Colonel Western in recent years, and the schemes of the future.

The Assiout barrage was commenced in 1898, and finished in 1902 at a cost, with subsidiary works of £869,546. It ensures a constant supply of water to Middle Egypt, and the Fayoum, doing for these districts what that at the apex of the Delta does for Lower Egypt. The width of the river at the site of the work was 900 metres (2,953 feet), the length of the dam is 833 metres (2,733 feet). The structure is an arched viaduct, resting on a broad solid masonry floor foundation. There are 110 piers, and the openings between them can be closed when necessary by iron sluice gates which slide in vertical iron grooves set in the sides of the piers. Two sluice gates, each 8 ft. 2 in. high are provided for each opening, and they are raised or lowered by overhead travelling winches running on rails the whole length of the barrage. A lock 52 ft. 6 in. wide is provided next the left bank for navigation.

The foundations are of masonry, forming a wide floor laid on the fine sand of the river bed, and sheet piling. Its bottom is 16 ft. 8 in. below the low summer level of the stream. The river level was about 25 ft. above the bottom of the floor at the commencement and termination of each season's work. Great difficulty was experienced here owing to the innumerable springs which burst out when the river bed was excavated; over a thousand large springs from 7 in. to 8 in. diameter being met with. At one time as many as twenty-eight centrifugal pumps of various sizes were at work excavating the water-saturated sand. The coal consumption for this work alone was 21,061 tons.

The river bed for a distance of 65 ft. 7 in. from the masonry floor on both the up and down stream side of the barrage is paved with rubble pitching. A roadway for traffic is carried over the barrage. A regulator is a subsidiary piece of work across the canal which conveys the waters from the Nile barrage to the lands to be irrigated.

The following quantities were used in the barrage and regulator. Rubble masonry and concrete 210,222 cubic yards, stone pitching 147,152 cubic yards, besides 642,370 cubic yards of temporary dams, rubble stone, sacks, and rope nets. The average number of men employed during the busiest season was about 7,500.

The dam at Assuan is a solid wall of granite masonry, pierced by 180 sluices, 140 being under sluices of 23 ft. by 6½ ft., and 40 upper sluices of 11½ ft. by 6½ ft. The total area of waterway is 24,000 square feet. The maximum flood of 475,000 cubic feet per second is discharged at a velocity of 20 ft. per second, and ordinary floods at a velocity of 16 ft. per second. Stoney self-balanced roller gates regulate the flow of water. Its total length is 2,750 ft., or rather more than half a mile. The piers and arches are founded on a platform of masonry 87 ft. wide, and 10 ft. thick, protected with cast-iron piling, with cemented joints, which goes down to a depth of 23 ft. below the upper surface of the floor into the sand bed of the river. Navigation is provided for by a ladder of four locks, each measuring 260 ft. by 32 ft. The reservoir can contain over 1,000,000,000 tons of water,

more than enough for a whole year's domestic consumption for the United Kingdom. This was completed in 1902.

Another barrage is that at Zifta on the Damietta branch of the Nile, midway between Cairo and the sea, opened in 1903. It is 408 yards long, comprising 50 arches, each 16½ ft. broad, and a lock 184 ft. long, by 40 ft. wide.

The 130 milliards of cubic feet of water supply still left unprovided for, when the Assuan dam shall have been raised to its full height, must come from the sources of the Nile. The question is one of money, for though the engineering difficulties are great, they can be overcome, and then the reclamation of the Soudan, with the Cape to Cairo railway would render all Egypt a fertile and valuable country.

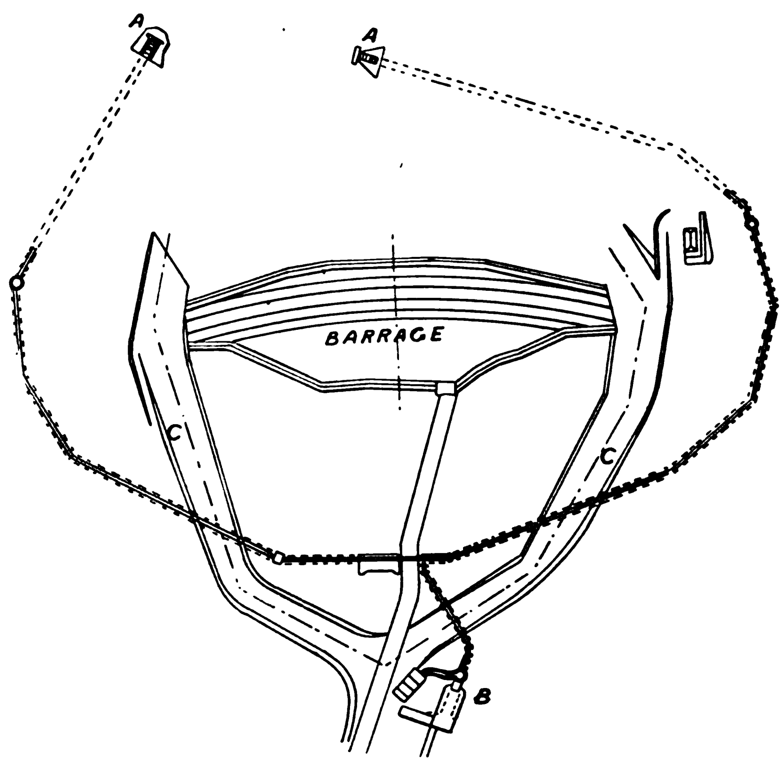


Fig. 72.—Plan of Gileppe Barrage.

A very deep barrage is that at Gileppe, Figs. 72 and 73, about 13 miles from Spa, built in 1867-1878. The hills surrounding the reservoir pour down vast quantities of


Fig. 73.—Longitudinal and Cross Sections of Gileppe Barrage.

a very pure soft water, which is impounded by the dam for the use of the town of Verviers, both for drinking purposes, and for the cloth factories. The dam carried across a narrow part of the valley of the Gileppe is 90 yards long, and 72 yards thick at the base, and 256 yards long, and 16 yards thick at the top. It contains 248,470 cubic metres. The height of the parapet is 154 feet. The dam is solid, that is, instead of being pierced with openings for the regulation of the supply, this is taken round it by two subterranean galleries in the form of a horseshoe. The reservoir contains 2,700 million gallons. Its area is 200 acres.

The water taken away by the two subterranean galleries is filtered through a grating A at the upper end of each, and thence through a gallery to the sluices. Here a mass of masonry encloses two cast-iron pipes 34 inches diameter, each of which is closed at the lower end by a self-acting valve. After passing the working chamber the water arrives at another masonry dam, below

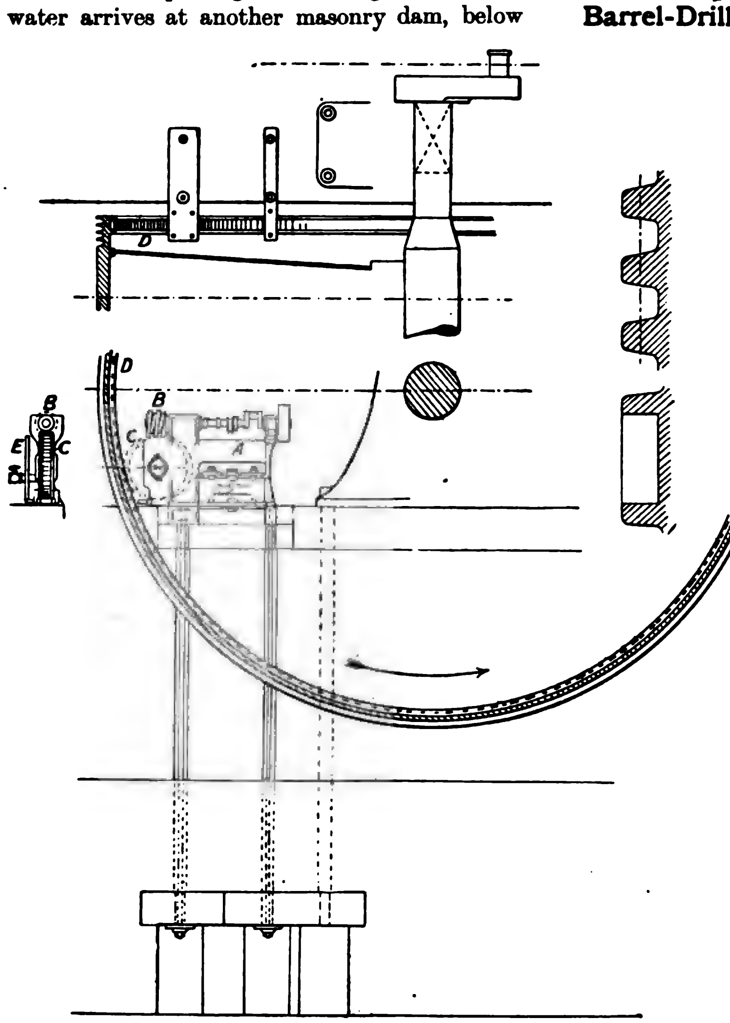


Fig. 74.—Barring Engine.

which is a safety sluice. Thence the water passes through a measuring apparatus B to the aqueduct. C, C, Fig. 72, are overflow channels. The cost of this work was 7,000,000 francs, or £280,000.

Barrel.—A term which has various significations. It is commonly applied to casks. It is a synonym for drum, as applied to cranes (*see* **Crane Drum**) whether of the plain, or the fusee type. It denotes the cylinder of a pump, a tumbling barrel for fettling castings, the tubular portion of a locomotive boiler as distinguished from the fire and smoke boxes, the shell of an internally fired boiler, as separate from the furnace tubes.

Barrel-Drilling Machine.—A special type of horizontal drilling machine, which though evolved primarily for gun-barrel work, is utilised extensively for other classes of deep drilling. Work of this kind can be done up to about 12 inch bore by 13 feet on these machines. The piece is revolved, and supported in bushed bearings, while the drill is fed in, a plentiful supply of lubricant being pumped along the drill body. The drill is attached to the end of a long bar or tube, the actual cutting portion consisting only of a small piece of steel. Guides are employed for steadying.

Lapping is another operation, which succeeds the drilling, being performed on somewhat similar machines. The barrel is slid to and fro while the lapping bar rotates in the bore.

Barrel Hoops.—The thin strips of steel which are rolled in strip mills for the hoops of casks, and of bales.

Barrel-Making Machines.—*See* **Cask-Making Machines.**

Barrel-Rifling Machine.—For rifling the barrels of guns, a special type of horizontal bed machine is employed. The barrel is gripped in an indexing chuck, which revolves for the correct number and spacing of grooves. The rifling bar is reciprocated back and forth, and is also given a twisting motion, which is variable, for different pitches. The bar is provided

with a special cutter, which is fed outwards automatically after each stroke, by means of a plunger, until the right depth of groove is reached. The average speed of cutting for ordinary steel is 30 feet per minute.

Barrel Stays.—Boiler stays for the barrels, as distinguished from those used in fire boxes.

Barring Engine.—A small engine fitted to nearly all mill engines, and large ones for electric light generation, which is rendered necessary by the great mass of these types of engines. The barring engine is used primarily for starting up, in place of "barring" round the flywheel by a pinch bar inserted in holes in the rim, the method commonly adopted in engines of medium dimensions. The object of the barring engine is more than this. Its function includes running the main engine for a short period until all parts are uniformly warmed up, moving it for the purpose of setting valves, for examining pistons and air pumps, &c., and for repairing, or putting on driving ropes and belts out of working hours.

The barring engine shown by Fig. 74 in its relation to the flywheel of the main engine is one by Hick, Hargreaves & Co., Ltd., of Bolton. It embodies an automatic disengagement which comes into play when the main engine begins to run quicker than the barring engine, as follows:—In Fig. 74 A is the barring engine (double cylinder in the example) the crank shaft of which drives the worm B. The wheel C indicated, in its "in," and "out of gear" positions by the dotted circles, has its teeth made as those of a worm wheel on one side—that driven by the worm—that is they are angled to suit the worm thread; and as a spur, square across, on the other—that which engages with the barring rack D. The in, and out position of the worm wheel is provided for by a slot (not shown) in the body casting, along which the wheel shaft may slide, and in its out of gear position can be held by two springs. A lever E furnishes the means by which the wheel is thrown. It holds a brake against the lower edge of the wheel, making it a fulcrum so that the rotating worm thrusts the wheel into gear with the barring rack. If the flywheel becomes the driver, the worm becomes the fulcrum, and the wheel slides back, and its shaft is retained there by the springs just now mentioned. When the barring engine is started there is no movement of the main engine until the lever is thrown in.

These engines are made to give either upward or downward thrust by simply placing the cylinders up or down, and altering the positions of the lubricators, and oil dish. The usual position is that shown in the figure, but this can be varied to suit different requirements.

For the majority of main engines the load when barring generally ranges from a fifth to a third the full power, but special cases, as those of some pumping engines, require more power. The following formula is given by Messrs Hick, Hargreaves & Co., Ltd., to obtain the average thrust in lb. required for a given main engine:—

$$\text{Average thrust in lb.} \left\{ \frac{\text{IHP. at full load and speed} \times 10{,}509 \times \text{fraction of full load when barring}}{\text{Revs. per minute at full speed} \times \text{diameter of barring rack in feet.}} \right.$$

A liberal margin of power should be allowed, because the barring engine often has to be used out of work hours, when the boiler pressure is run low. These engines are designed for a working pressure of 100 lb. per square inch. Single cylinder engines as well as double are made.

Barring Rack.—The rack on the fly or rope wheel of a main engine in which the worm wheel of the barring engine engages. Pitches range from 3 in. to 5 in. The section used by Messrs Hick, Hargreaves & Co., Ltd., is shown in Fig. 74 full shrouded on each side.

Barrow Ladle, or Carriage Ladle.—A small foundry ladle mounted on a frame, having two front wheels, and two legs and handles behind. The shank turns in a socket, so that the ladle can be tilted to either side. Their capacity usually ranges from 2 to 4 cwt.

Barrow Pump.—A pump mounted for convenience on a hand barrow. Often termed a proving pump, and a California pump.

Bar Shears, or Bar Cropping Shears.—Shearing machines designed specially for cutting off bars of square, oblong, and round sections.

what the old wheel rope did, and the motion of which is controlled from the bridge, the conning tower, or any other convenient place, by a rope winding on a drum, and having a wheel with spokes, like the old steering wheel, the rope working the valve controlling the admission of steam to the cylinders of the engine. The steam steering engine, again, is threatened with displacement by the electrical steering apparatus. In foreign navies, at least, where steam steering gear is fitted, an electrical repeating apparatus is provided, showing in the captain's cabin, the conning tower, the bridge, and other places, as may be arranged, how the helm is at each instant. The anchor also, was, in the old days, pulled up by the capstan, by means of an endless rope, or chain, called the messenger, running continuously round the capstan and sheaves in the forepart of the ship, the cable being lashed to a portion of the messenger, and so pulled in, the catting and fishing being done by ropes passing through immense blocks. It is now pulled up by a steam capstan, acting directly on the chain cable, and is pulled right up to the hawse pipe. The capstan engine is also placed on the forward part of the ship, whereas the old capstan was on the quarter-deck, as it was necessary to give the messenger room to work. The steam capstan is giving way to the electric capstan, though we do not know of any instance of its adoption in British battleships.

The boats of the modern warship are hoisted up, and where required, as in the case of the large launches and torpedo boats carried by battleships, right inboard, the work being done by derricks, arranged to swing inboard and outboard at will, each derrick being worked by its own engine; the derricks take the place of the old davits.

Working the Guns.—Many of the guns in a modern battleship are fixed in turrets, circular structures carried on the upper deck, arranged to revolve, presenting a gun port for the egress of the muzzle of the gun, when it is to be fired, and shielding the crew while loading is going on. The turret is revolved by hydraulic engines, and the sponge and rammer used in loading are lifted by tackle worked by hydraulic power, the charge and the projectile being also lifted to the muzzle of the gun in the same way. Hydraulic power for this purpose is giving way to electric power, electric motors being used for all the above. Where hydraulic power is used, an hydraulic plant is necessary, consisting of the necessary pumps, and storage tank, with its pressure arrangements, and distributing pipes. Electricity is finding more favour, as it is being better understood, on account of the smaller size of the distributing conductors, and the greater flexibility of the system generally.

While on the matter of the guns, it may be mentioned that they are always now fired electrically, a detonator being inserted in the vent hole, in connection with the cartridge, and fired by a spark passing between two wires embedded in the detonating mixture. The current for the detonator is supplied from any convenient source, and is under the control of the gunnery officer, or the captain, in the conning tower, but is also arranged to be fired from the turret itself. The arrangement for firing the remainder of the guns is the same. Ammunition is brought to the turrets, the batteries, and the firing tops on the masts, by means of ammunition hoists, practically small winches, now usually worked by electric motors. Small guns are carried in the firing tops.

Cold Storage.—No modern battleship is complete, in foreign navies at any rate, without a cold storage plant, consisting of a carbonic acid compressor, with the necessary adjuncts, and cold chambers, for keeping provisions for the officers and crew. Advantage is sometimes also taken of the presence of cold storage plant to cool the air for the officers' and crews' quarters, the magazines, and other parts, and to dry the air where necessary, or moisten it, if required. In the Japanese battleship mentioned above, what is known as the Thermo-tank system has been applied, in which the air passes through a vessel, something similar to an evaporator, in which it can be warmed, cooled, dried, or moistened, and thence passed into the ship.

The Torpedo Equipment.— Every modern battleship carries a certain number of torpedoes, for which compressed air is required, and therefore an air compressor, with its driving engine, forms another necessary part of her equipment.

Compressed air is used in the torpedo itself to launch it, and to propel it through the water after it has been launched. The torpedo is an apparatus shaped like a fish, with a screw propeller in its tail, a fuse in its nose, compressed air engines near the tail to work the screw, and a charge in the front to damage the vessel struck. It is projected from the side, or stern of the ship, through a tube, which is usually under the water line, and hence the necessity of force to eject it.

Electric Light and Power.—The modern battleship is lighted throughout with incandescent electric lamps, and it has also a number of very powerful arc lights, known as search lights, fixed in various parts of the ship, where they can be of service, their office being to detect the approach of hostile ships, such as torpedo boats, &c. In addition, as already mentioned in several cases, many of the machines used in a battleship are worked by electric motors, and the number is increasing constantly. Hence every battleship carries two electric generating stations, one for regular work in peace, the other, below the water line, for use in action. The generators and motors used are of the continuous current type, and are, or have been till very recently in the British Navy, worked at a pressure of 80 volts, the currents being distributed from the switchboard in the generating station to the lamps and motors by armoured cables. The arrangement of the armoured cables, and their passage through the watertight partitions, is one of the most difficult parts of the work of electrical distribution in the modern battleship. Holes have to be cut in the partitions for the passage of the cables, and sometimes in the decks, and the holes have to be carefully made good after the cables are in place.

Repairs.—Being a mass of machinery, the modern battleship necessarily carries a repairing shop, a fitting shop as it would be called on shore, with every kind of tool likely to be required for repairing any of the numerous machines and engines mentioned; and the tools are driven by their own workshop engine, now giving way to the electric motor. Telegraphs, telephones, speaking tubes, and other arrangements for communicating between different parts of the ship are also fixed, but there is great difficulty in making delicate electrical apparatus, like telephones, work under ordinary conditions, on board a man-of-war, and it is practically impossible in action. It is stated that in one of the recent Russo-Japanese actions, the Russian captains were obliged to have their orders written in chalk on boards and sent to the guns' crews.

Bauer Coke Ovens.—*See* **Coke Ovens.**

B. A. Unit.—British Association Unit or **Ohm**, determined in 1863.

Bauxite. Bauxite Bricks.—A refractory material made into bricks for the lining of melting furnaces. The calcined bauxite is mixed with clay or plumbago. Bauxite is a hydrated alumina ferric oxide containing about 60 per cent. of alumina, 20 per cent. of ferric oxide, 15 to 20 per cent. of water, and from 1 to 3 of silica.

Bay.—The area enclosed by the triangulation of bridge members. Also the longitudinal division comprising the departments of shops under different roof spans.

Bayonet Engine.—A horizontal engine in which the bed plate is curved round to clear the crank disc.

Bayonets.—These are made in dies and rolls. The neck is formed in dies. At the termination of the neck there is an enlarged portion to which the socket is to be welded later. The blade is gradually drawn down in a set of special rolls having about nine grooves. It is then placed in a box of charcoal to be annealed. Subsequently a heat is taken at the neck, which is bent to a right angle and the socket, already prepared of iron, is welded to it, followed by annealing and grinding.

Baywood.—*See* **Mahogany.**

B, or **Best.**—The poorest quality of bar iron.

B, B, or **Best, Best.**—The second quality of bar iron.

B, B, B, or **Best, Best, Best.**—The best quality of bar iron.

Bead.—A moulding of semicircular section. Denotes also various fillets on castings.

Beading.—The imparting of a convex edge to the ends of boiler tubes after they have been inserted, and riveted in the tube plates. It is

done by hammering, using a concave tool, and by an **Expanding Tool**.

Beading Tool.—A tool used for beading. It has a concave shoulder at a short distance away from its end, which is hammered against the end of the tube, so finishing it neatly.

Bead Sleekers, or **Bead Tools.**—Moulders' finishing tools which are convex in both directions, for smoothing the beads of moulds. The concave scraping tools used by iron turners are often termed bead tools.

Beak Iron.—*See* **Bick Iron.**

Beam.—A beam is any detail of a machine or structure that is subjected to bending action by forces applied to it transversely or obliquely at some distance from its supports. Such forces produce reactions or balancing forces at the supports as well as a *bending moment* and a *shearing force* at each transverse section of the beam.

The span of a beam is the distance between the centres of its supports.

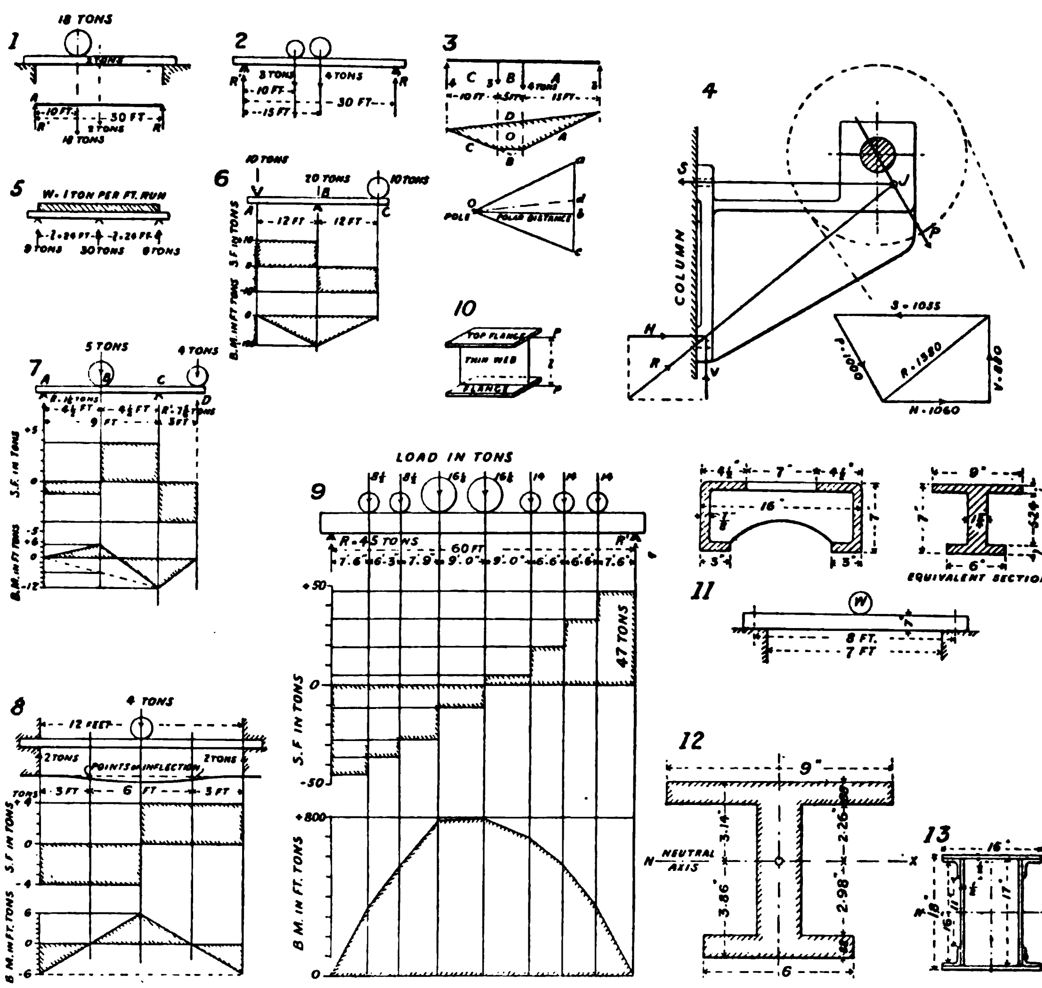


Fig. 81.—Diagrams of Stresses in Beams.

An overhanging beam is termed a cantilever.

Determination of Reactions due to given Applied Forces.—Reactions may be found either arithmetically or graphically, the usual methods being shown in the following examples:—

Example 1.—Diagram No. 1 on the sheet of figures, Fig. 81, shows a beam weighing 2 tons

supported at both ends, and loaded with 18 tons at 10 feet from one support.

The reactions R and R^1 are found by applying the principle of the lever; viz., by taking moments about one end, say A, and forming an equation thus—

$$\left.\begin{array}{l}\text{Moments tending to}\\\text{turn the beam one}\\\text{way round}\end{array}\right\} = \left\{\begin{array}{l}\text{Moments tending to}\\\text{turn the beam the}\\\text{opposite way round.}\end{array}\right.$$

Thus, in the present case,

$$R \times 30 \text{ feet} = 18 \text{ tons} \times 10 \text{ feet} = 180 \text{ foot-tons},$$
$$\therefore\ R = 6 \text{ tons}; \text{ and } R^1 = 18 - 6 = 12 \text{ tons}.$$

Thus, disregarding the beam's own weight, the reactions are inversely proportional to their distances from the load. The weight of the beam is taken into account by adding 1 ton to each reaction, the beam being symmetrical.

Example 2.—To find R and R^1 in Diagram No. 2, we have

$$R \times 30 \text{ ft.} = (4 \text{ tons} \times 15 \text{ ft.}) + (3 \text{ tons} \times 10 \text{ ft.}),$$
$$\therefore\ 30\ R = 60 + 30 = 90,$$
$$\therefore\ R = 3 \text{ tons}.$$

Hence $R^1 = 7 - 3 = 4$ tons.

As an alternative, we may use Culmann's graphical method of finding reactions, as follows:—Letter the spaces between the external forces, as in No. 3, according to Bow's excellent system. Set off $ab = 4$ tons, and $bc = 3$ tons to any convenient scale. Select any point O, called the "pole," and join O*a*, O*b*, O*c*. Produce the vertical lines of action of the forces, and, beginning on any of these lines, draw OA, OB, OC, in the link polygon parallel to the corresponding lines in the polar diagram. Draw the closing side of the polygon OD, and the dotted polar line O*d* parallel to it. Then the required reactions are *cd* and *da* to the force scale. Also the intersection of OA and OC, in the link polygon, fixes the line of action of the resultant of the loads. A feature to be noted is the relationship of the three diagrams as regards lettering.

Example 3.—To find the reactions or external forces on a bracket required to balance a pull of 1000 lb., inclined at 30° to the vertical, due to the tension of a belt.

Looking at Diagram 4 we see that to balance P there must be a horizontal pull S on the wall or column at the top row of bolts; also a horizontal thrust H at the bottom, and lastly a vertical force V coming on either the bolts, or a lip on the column carrying the bracket. Now H and V have a diagonal resultant R, which must pass through the intersection J, of the directions of P and S. We then have three balancing forces at J, and therefore easily find R and S by drawing to scale a triangle of forces. Resolving R horizontally and vertically, as shown in the force polygon, we finally get H = 1,060 lb. and V = 880 lb., as shown.

Reactions in the case of Continuous Beams.—A beam resting on more than two supports is said to be *continuous*. For such beams the above methods fail to give the reactions, so that another method of calculation, termed the "Theorem of Three Moments," must be adopted. The most usual case is that of a beam of uniform section, loaded with *w* tons per foot run, and resting on three supports at the same level (Diagram 5). Then the reactions at A and B are $\frac{3}{8}\,wl$, while the reaction of the central pier C is $\frac{5}{4}\,wl$. Thus if the spans are 24 feet and the load is 1 ton per foot run, then

the end reactions are $\frac{3}{8} \times 1 \times 24 = 9$ tons, and
the central reaction is $\frac{5}{4} \times 1 \times 24 = 30$ tons.

In the case of a continuous beam of three equal spans, the reactions of the two *outer* supports are $\frac{4}{10}\,wl$, and of the two *inner* supports $\frac{11}{10}\,wl$. Any variation in the level of the supports affects the magnitude of the reactions; but the flexibility of the beam enables it to adapt itself to some variation of level of its supports. Owing to the large proportion of the load borne by the inner supports or piers, it is not advisable to use continuous beams where the foundations of the piers cannot be fully relied upon. For long spans, continuous beams are more economical than discontinuous beams.

Determination of Shearing Force and Bending Moment.—The *vertical shearing force* at a given section of a beam, loaded in any manner, is defined as the resultant of all the forces acting on one (either) side of the section resolved vertically. The vertical shearing force is always accompanied by a horizontal shearing force of equal magnitude.

The *bending moment* at any transverse section of a beam is defined as the algebraic sum

or resultant of all external forces acting on one side of that section. It represents the influence tending to bend or deflect, and ultimately to rupture the beam. This bending moment is wholly external to the beam, its magnitude being governed only by the nature of the loads and their position along the beam. It has no reference to the cross-section or to the material of the beam. In flanged beams the S.F. is resisted mainly by the web and the B.M. by the flange.

Diagrams of shearing force and bending moment show very clearly how the shearing force and bending moment vary from point to point in the length of a beam, and the method of constructing them may be conveniently given at the same time as the arithmetical calculation of these quantities.

Consider first the simple case of an overhanging beam or cantilever, Diagram 6, loaded at the free end.

Let us agree that forces acting upwards shall be regarded as positive, and the contrary negative, while moments tending to make the beam concave upwards are positive, and the contrary negative. Thus sagging moments are positive, and hogging moments are negative. To preserve consistency of sign we must restrict our attention to the right-hand side of the section of the beam under consideration. It should be observed that the inclination of the bending moment curve, as measured by the tangent of the angle of slope, is a measure of the shearing force, but opposite in sign, a connection which enables us to derive one curve from the other.

Between points B and C (Diagram 6) the shearing force is obviously uniform and $= -10$ tons, this being the only force acting to the right of B. From A to B the shearing force is equal to the upward reaction of 20 tons *plus* the downward load of 10 tons; *i.e.*, $20 - 10 =$ 10 tons. These forces are represented in the diagram by the equal ordinates of two parallel straight lines.

The bending moment at B is 10 tons × 12 feet = 120 foot-tons. The bending moment increases uniformly from zero at C to this maximum value. At a point midway between A and B the bending moment will be $(-10 \text{ tons} \times 18 \text{ feet}) + (20 \text{ tons} \times 6 \text{ feet}) = -180 + 120 = -60$ foot-tons. The bending moment at any other section is shown by the height of the corresponding ordinate of the bending moment curve, which in this case consists of two equally inclined straight lines.

No. 7 shows the diagrams of shearing force and bending moment for a beam with a load of 5 tons at B, half-way between its supports, and 4 tons overhung at D.

The case of a beam *built in* at each end is represented in No. 8. This corresponds to two cantilevers of length $= \frac{1}{4}$ L, supporting a beam of length $= \frac{1}{2}$ L. The shearing force is the same as when the beam is merely supported at the ends.

No. 9 represents a girder of 60 feet span, loaded with a bogie express engine and tender weighing 92 tons.

Taking moments to find the reactions, we get

$$60R^1 = (8\tfrac{1}{2} \times 7\tfrac{1}{2}) + (8\tfrac{1}{2} \times 13\tfrac{3}{4}) + (16\tfrac{1}{4} \times 21\tfrac{1}{2}) + (16\tfrac{1}{4} \times 30\tfrac{1}{2}) + (14 \times 46) + (14 \times 39\tfrac{1}{2}) + (14 \times 52\tfrac{1}{2})$$

$$= 2820 \quad \therefore \; R^1 = \frac{2820}{60} = 47 \text{ tons}$$

and $R = 92 - 47 = 45$ tons.

The bending moment at $C = (45 \times 21{\cdot}5) - (8\tfrac{1}{2} \times 14) - (8\tfrac{1}{2} \times 7{\cdot}75) = 781$ foot-tons. The bending moments at the remaining points are calculated in a similar manner.

Determination of Moment of Resistance.—The moment of resistance to bending of a given section of a beam is the measure of the capacity of that section to resist the bending moment. Its value entirely depends on the size and shape of the section and on the kind of material composing the beam.

The simplest case is a deep girder with thin flanges connected by a thin web (No. 10). Here the moment of resistance is the total *pull* P on the fibres composing the lower flange multiplied by the length of the resistance arm l, this being the distance between the centres of area of the two flanges, or the effective depth of the girder.

Thus if the flanges are 10 inches wide by 1 inch thick, and the effective depth of the girder 30 inches, while the stress allowed is 8,000 lb. per square inch, then $P = 10 \times 1 \times 8{,}000 = 80{,}000$ lb., and the moment of resistance

$$M = P \times l = 80{,}000 \text{ lb.} \times 30 \text{ in.}$$
$$= 240{,}000 \text{ inch-pounds.}$$

This method is sufficiently accurate for plate girders.

In the case of a rectangular beam the moment of resistance is given by the relation

$$M = \tfrac{1}{6}\, bh^2 \times f$$

where b inches = breadth of beam
h inches = depth of beam
f lb. per sq. in. = safe stress.

The general conclusions to be inferred from this formula are the following:—

(1) The resisting capacity or strength of a rectangular beam is directly proportional to its *breadth*; so that doubling the breadth of a beam also doubles its strength, all other things being unaltered.

(2) The strength of a beam is directly proportional to the square of its *depth*; so that doubling the depth quadruples the strength. Increase of strength is therefore most economically gained by increase of depth.

(3) The resistance of a beam is directly proportional to the stress put on the outside fibres, so long as this stress does not exceed the elastic limits of the material.

Strength Modulus of a Section.—The above formula for the moment of resistance of a rectangular section may be split up into two parts. The part f refers to the safe stress per square inch allowed on the material, and has nothing to do with the shape of the section. The other part takes account of the shape and size of the section, and is conventionally referred to as the strength modulus of the section with respect to bending, a term introduced by Professor Unwin. This quantity is symbolised by the letter Z. Hence for *any* section of a beam, moment of resistance

= modulus of section × stress;

or, $M = Z \times f$.

Each shape of section has its own particular strength modulus, according to the disposition of the material with respect to the neutral axis. Unsymmetrical sections have *two* moduli, one for tension and one for compression.

The modulus of a circular section of diameter D is $\frac{\pi}{32}D^3$, which is very nearly $\frac{1}{10}D^3$. Thus in the case of a beam 12 inches diameter

$$Z = \frac{\pi}{32} \times 12^3 = 170 \text{ inch}^3.$$

If the safe load be 6 tons per square inch, then moment of resistance

$$= Z \times f = 170 \times 6 = 1020 \text{ inch-tons.}$$

General Method.—The following example will serve to illustrate a general method of finding the moment of resistance of a beam of any section.

Diagram No. 11 shows a proposed section of a beam to carry a motor. It is required to find the safe load at the centre, the effective span being 8 feet.

(1) Reduce the section to a simple equivalent section (Diagram 11).

(2) Find the position of the neutral axis, by taking moments about the bottom edge (Diagram 12), thus—

Dimensions.	Area.	Arm.	Moment.
Inches.	Sq. Inches.	Inches.	Inch³.
$9 \times 0{\cdot}88$	7·92	6·56	52·0
$1\tfrac{3}{4} \times 5{\cdot}24$	9·18	3·50	32·2
$6 \times 0{\cdot}88$	5·28	0·44	2·3
...	22·38	...	86·5

Hence the distance ($\bar{y}$) of the neutral axis from the bottom edge

$$= \frac{86{\cdot}5}{22{\cdot}38} = 3{\cdot}86 \text{ inches.}$$

(3) Find the moment of inertia of the section about the neutral axis, NX in No. 12. (The moment of inertia of a section is equal to the strength modulus multiplied by the distance of the extreme fibres from the neutral axis.)

The moment of inertia (I_1) of the upper par of the section about the neutral axis is

$$(\tfrac{1}{3} \times 9 \times 3{\cdot}14^3) - (\tfrac{1}{3} \times 7{\cdot}25 \times 2{\cdot}26^3)$$
$$= \tfrac{1}{3}\,[(9 \times 31) - (7{\cdot}25 \times 11{\cdot}5)]$$
$$= \tfrac{1}{3}\,(279 - 83{\cdot}5)$$
$$= 65 \text{ inch}^4 \text{ or } 65 \textit{ quartic} \text{ inches.}$$

Similarly, the moment of inertia (I_2) of the lower part of the section about the neutral axis is

$$\tfrac{1}{3}\,[(6 \times 3{\cdot}86^3) - (4{\cdot}25 \times 2{\cdot}98^3)]$$
$$= 77 \text{ inch}^4.$$

Therefore, the moment of inertia (I) of the whole section about the neutral axis

$$= I_1 + I_2 = 65 + 77 = 142 \text{ inch}^4.$$

Now $Z_c = \frac{I}{y_c} = \frac{142 \text{ inch}^4}{3\cdot 14 \text{ inches}} = 45\cdot 2 \text{ inch}^3$, which is the strength modulus of the section as regards compression.

Also $Z_t = \frac{I}{y_t} = \frac{142 \text{ inch}^4}{3\cdot 86 \text{ inches}} = 36\cdot 8 \text{ inch}^3$, which is the strength modulus of the section as regards tension.

Now, the bending moment

$$= \frac{WL}{4} = \tfrac{1}{4}\, W \times 96 = 24 \text{ W}.$$

Allowing f_t = safe tensile stress = 3,000 lb. per square inch, we have

$$f_t \times Z_t = 24 \text{ W}$$

$$\therefore \quad 3000 \times 36\cdot 8 = 24 \text{ W}$$

$$\therefore \quad W = \frac{3000 \times 36\cdot 8}{24} = 4{,}600 \text{ lb.},$$

which is the safe central load sought.

It is unnecessary to calculate what would be the safe load as regards compression, it being obvious that the beam is weaker as regards tension than as regards compression, and would therefore fail at the tension flange before the superior strength of the compression flange could be utilised.

The Deflection of Beams.—When an originally straight beam is loaded by a force of sufficient magnitude, the beam visibly *bends* or assumes a curved form, and the load falls through a certain height. This vertical movement is styled the *deflection* of the beam. The amount of deflection varies from point to point, but its greatest value is alone important, and this is what is ordinarily meant by the deflection of the beam.

The general formula for calculating the maximum deflection of any beam of uniform section, when loaded in any simple or standard manner, is the following:—

$$\text{Deflection} = C \times \frac{WL^3}{EI}.$$

The deflection is expressed in inches. L is the length of the beam unsupported, in inches. W is the load or force applied, either in tons or pounds. The formula ceases to be true when W exceeds the elastic limit load, the stress due to a given load being calculated by the equation—

Bending moment = stress × modulus of section.

I is the geometrical moment of inertia of the section with respect to its neutral axis, expressed in quartic inches (inch^4). E is the modulus of elasticity of the material, or ratio of stress to strain within the elastic limits. This is a measure of the *stiffness* of the material.

C is a numerical co-efficient whose value depends on the mode of supporting and loading the beam as under—

Case.	How Supported.	Position of Load.	C.
1	Fixed at one end - -	At free end - -	$\frac{1}{3}$
2	Do. do. - -	Uniformly distributed	$\frac{1}{8}$
3	Supported at both ends	At centre - - -	$\frac{1}{48}$
4	Do. do.	Uniformly distributed	$\frac{5}{8} \times \frac{1}{48}$
5	Fixed at both ends -	At centre - - -	$\frac{1}{5} \times \frac{1}{48}$
6	Do. do. -	Uniformly distributed	$\frac{1}{8} \times \frac{1}{48}$

Thus the stiffness of a beam is greatly increased by firmly securing the ends.

Deflection of Rectangular Beams.—Since the moment of inertia of a rectangular section about the neutral axis is—

$$\tfrac{1}{12} BH^3,$$

for a beam of this shape supported at both ends the general deflection formula becomes

$$d = \frac{1}{48} \times \frac{WL^3}{E} \times \frac{12}{BH^3}$$

$$= \frac{W}{4E} \times \left(\frac{L}{H}\right)^3 \times \frac{1}{B}.$$

This important formula shows that the deflection of a beam under a given load varies

inversely as the breadth of the beam and directly as the cube of the ratio of the span to the depth. Hence to secure sufficient stiffness long beams require to be made very deep.

Example.—A wrought-iron girder of the section shown in No. 13, and of 30 feet span, weighs 2 tons, and carries a uniform load of 13 tons. Calculate the probable deflection at the centre.

If there were no joints in this girder, we should take 13,000 tons per square inch as the modulus of elasticity of wrought iron; but for a riveted girder like the present, the usual value taken is 8,000 tons, to allow for the inevitable yielding of the joints.

The moment of inertia of the section about the neutral axis is 2,273 quartic inches. Inserting the proper values in the deflection formula—

$$d = \frac{5}{8} \times \frac{WL^3}{48EI},$$

we get

$$d = \frac{5}{384} \times \frac{15}{8,000} \times \frac{360^3}{2,273} = 0 \cdot 5 \text{ inch.}$$

This is also the amount of initial camber that should be given to the beam during construction.

Beam Bending Machine or Beam Straightening Machine.—Denotes a large group of machines designed for bending or straightening channels, joists, angles, and other sections, by the exercise of pressure between three points. Many of these are operated by a screw and large hand wheel, but the work of large shops is best served by the power machines driven either by belt, by an engine direct, or by motor as in the illustration, or by direct hydraulic pressure.

The three-point device is simple (see the diagram above Fig. 82). Two abutments, the distance apart of which is regulated by screws, react against the graduated pressure of a moving ram situated midway between them. The beam being placed against the abutment, is bent, or straightened by regulating the pressure of the ram against it. The adjustment of the abutments permits of imparting either a definite curve, or of straightening any length of section within the range of adjustment.

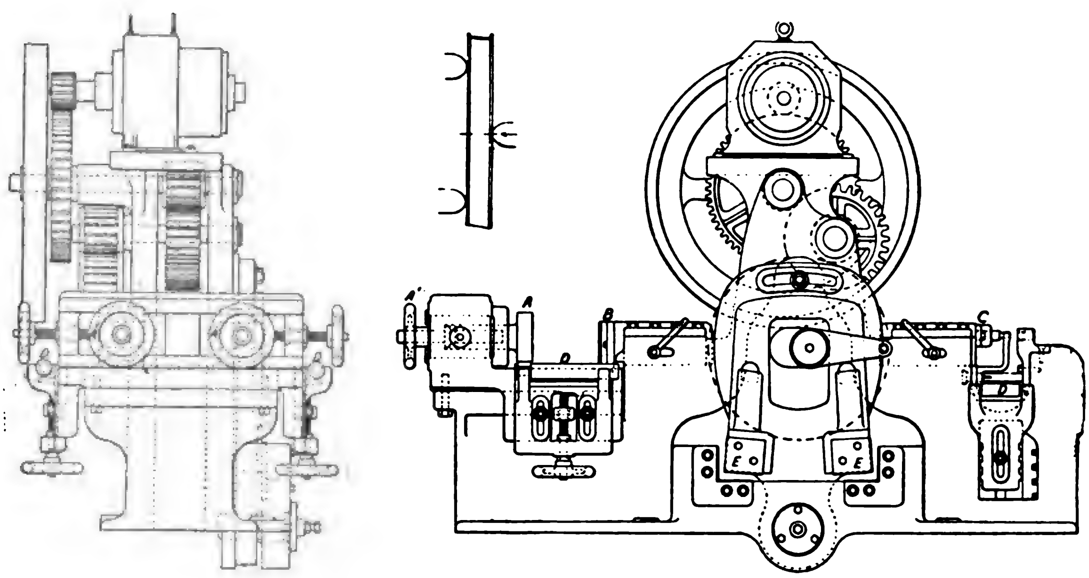


Fig. 82.—Beam Bending Machine. (Rushworth & Co., Sowerby Bridge.)

The larger machines, like that shown in the illustration, usually combine the function of punching, and of angle iron cutting, with that of bending, and straightening. The machine is thus double-ended, while the angle cutting is done at one side, and the angle shears are double for convenience of inserting either end of an angle. Riveting can also be done at

the punching end by inserting cupped closing dies.

The details of the machine are apparent. The two abutments, adjustable from 16-inch to 26-inch centres, with their hand wheels are shown at A A¹, and the moving ram at B. These with the punching ram C are driven from a steel eccentric shaft through double gear, and they are fitted with the usual stop motions. The beams are carried on rollers D D, adjustable vertically. E E are the angle shears. This particular machine will bend or straighten beams to 14 inches deep, punch 1-inch holes in 1-inch plate, 10 inches from the edge, cut angles 6 in. by 6 in., or flat bars 7 in. by 1 in.

Beam Calipers.—A form of caliper, which comprises a beam, having a sliding head, provided with means of clamping at any desired position. The end of the beam is extended into

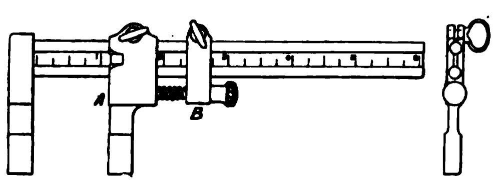


Fig. 83.—Beam Calipers.

a jaw, as is also the head, and the work is measured between the faces of these two. The advantage of the design is that graduations may be placed on the beam, and exact measurements taken, which is not the case with the ordinary leg calipers. The latter, however, embrace diameters which the beam caliper cannot tackle, unless the jaws stand out to an excessive amount.

The rougher classes of measurements can be taken by simply sliding the head along to the division required, and clamping there. For finer work some sort of screw adjustment is essential; this is met by the fitting of a separate auxiliary head, or push block (*see* Fig. 83, B), which is first tightened on the beam, and its screw altered as necessary to move the head A minutely to the required location. The illustration is that of a caliper with ribbed beam, having divisions (the finer ones of which are omitted) on the flat face. The majority of calipers have a plain flat beam, graduations being frequently located on both sides. A refinement consists in the fitting of a vernier, enabling delicate settings to be made. *See* **Vernier Caliper.**

Other variations in beam calipers comprise the inclusion of both internal and external jaws on opposite sides of the beam, so that inside and outside sizes can be measured. Points are also sometimes employed, to take measurements like a trammel.

Beam Compasses.—*See* **Trammels.**

Beam Engine.—The beam engine was the earliest type of steam engine. It derives its name from the oscillating beam which transmits the motion from piston to crank shaft, and which in the ordinary type is pivoted overhead. One end of the beam is moved up and down by the travel of the piston, and the other end, through the medium of a vertical connecting rod or pitman, transmits the motion down to the crank and shaft below. In this design parallel motion is necessary to permit the piston rod to maintain its rectilinear motion while the end of the beam to which it is connected follows a circle arc. The features peculiar to the beam engine were originally devised to suit the method by which the engine was worked, and the purpose it was used for, but they have proved so satisfactory in themselves that they are still retained in some modern engines, and have prevented the beam engine from becoming quite obsolete.

When the beam engine was first devised, the idea of obtaining rotary motion by means of a crank and shaft at the end of the connecting rod had not occurred to anyone; and the object of having an oscillating beam, was solely to impart direct vertical motion to a pump rod, which could not conveniently be attached directly to the piston itself, the engine being used for pumping water from mines. Owing to the peculiar method of working the original form of engine, a vertical cylinder was a necessity. Atmospheric pressure did the work originally, and steam was only used as a convenient means of producing a vacuum against which the atmosphere would exert pressure. In the early engines the top of the cylinder above the piston was entirely open to the atmosphere. The engine was balanced so that the normal position of the piston was always at the top of the cylinder. With the

piston in this position the lower part of the cylinder was filled with steam. It had been found that steam from boiling water exerted the same pressure as air, and that when it was condensed it left a vacuum. To work the engine at a reasonable rate it was necessary to condense as rapidly as possible. This was also necessary for the further reason that pistons then could not be made an air-tight or steam-tight fit. After crude attempts at cooling from the outside it was found that a spray of cold water inside the cylinder was by far the most effective means of condensing. As soon as the steam was condensed, atmospheric pressure forced the piston to the bottom of the cylinder. Fresh steam was then admitted below and the piston was pulled to the top of the cylinder again by the extra weight on the pump side of the beam. As the pull occurred alternately from the cylinder and from the pump, chains instead of connecting rods were all that was necessary, and even piston rods might have been dispensed with. This was Newcomen's engine, and was the first that was of any practical use. It was introduced about 1712, and minor improvements were made on it for over half a century, when Watt's inventions rendered it obsolete, and gave us the beam engine essentially as we have it at the present time.

The first and most important improvement which Watt made was to condense in a separate vessel instead of in the cylinder. This prevented the extreme waste of heat, and the unsatisfactory results of alternately cooling and reheating the cylinder. If this improvement had not been possible, condensing engines would have ceased to exist when the Newcomen engine was superseded. When the cylinder could always be kept as hot as the steam, it was soon seen that it would be better to cover the top and use steam as the motive power instead of air. The necessity of rigid connection between the piston and the beam to enable the beam to be alternately pulled and pushed was apparent, and for this purpose Watt devised the parallel motion, which is generally preferred to the use of guide bars for the crosshead of the piston rod. The air pump was a necessary adjunct to the separate condenser. The general working system of the engine was invented and arranged by Watt so perfectly that no important improvements have been possible since.

Two modifications of the overhead beam,—the side beam, and the lever engine have been made. In the first of these there is a beam on each side of the engine worked by transverse extensions from the crosshead of the piston rod. In the second the beam is pivoted at its end instead of its centre, and the rod which drives the crankshaft is attached at a point between. The object of these modifications was to reduce the engine to a more compact form suitable for steamships. The original form, however, has held its own, except where it has been displaced by new types which are not beam engines. The beam engine is not very commonly used now, but it is regarded as economical for the work it is suited for. It is used for pumping, and to some extent for driving machinery in factories, and it is the engine generally used on American paddle steamers. The general arrangement and method of working is as follows.

The cylinder stands on its end with the piston working vertically. The beam is erected horizontally at a suitable distance overhead, its centre provided with trunnions fitting in bearings on each side of the beam, and these bearings are suitably supported to carry the weight of the beam. The cylinder is situated below one end of the beam, and the crankshaft below the other. Besides the rods at the ends of the beam which make the connections between these parts, there are pump rods attached at intermediate parts, and pumps are arranged to come beneath them. There are usually three pumps worked in this way: the air pump, the cold water pump, and the boiler feed pump. The condenser is situated in a tank of cold water in proximity to the cylinder, and the exhaust passages from the latter lead into the condenser. The condenser of a beam engine is almost invariably of the jet type. The air pump, which is situated in the cold water tank by the side of the condenser, pumps air and water out of the condenser and draws it up into the hot well. This maintains a vacuum in the condenser which draws the steam from the cylinder as soon as the exhaust is

open. The result of this is that the incoming steam on the other side of the piston has only a vacuum to work against. The feed pump supplies the boiler with water from the hot well, and an overflow pipe in the hot well prevents the water from rising above a certain level. The cold water pump supplies the tank with water, which passes in a spray into the upper part of the condenser. These arrangements for condensing are applied to other engines besides those of the beam type, but it was with these that condensing originated, and

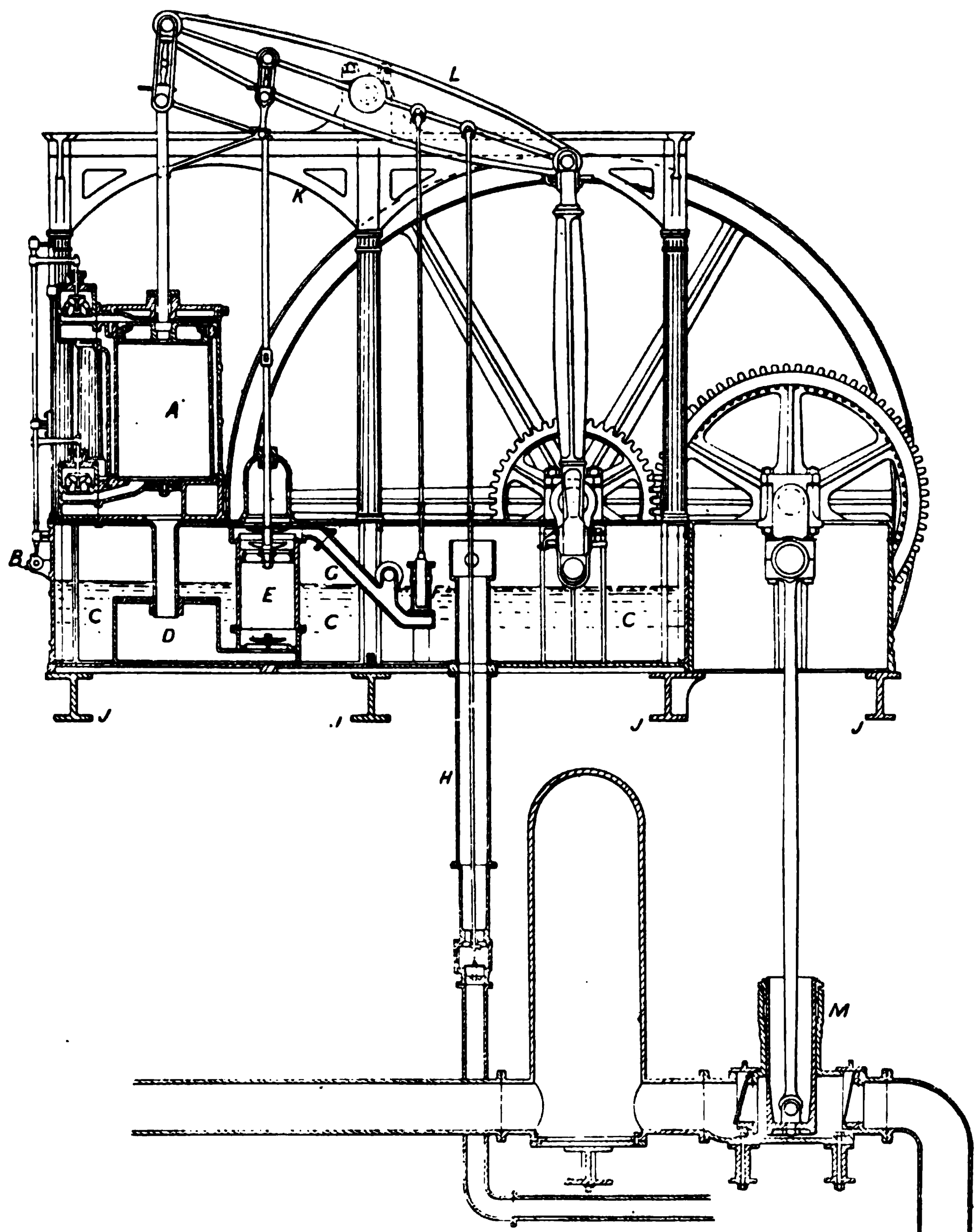


Fig. 84.—Beam Engine. (Sectional Elevation.)

a beam engine is always a condensing engine. Steam is always used very expansively in them; sometimes by early cut-off in one cylinder, or sometimes by exhausting from a high pressure cylinder into a low pressure before the steam passes to the condenser.

Figs. 84, 85 illustrate a beam engine which differs in several details from the usual types illustrated. The drawings are those of one constructed by Messrs James Watt & Co., Soho, Birmingham, for the Moscow Water Works.

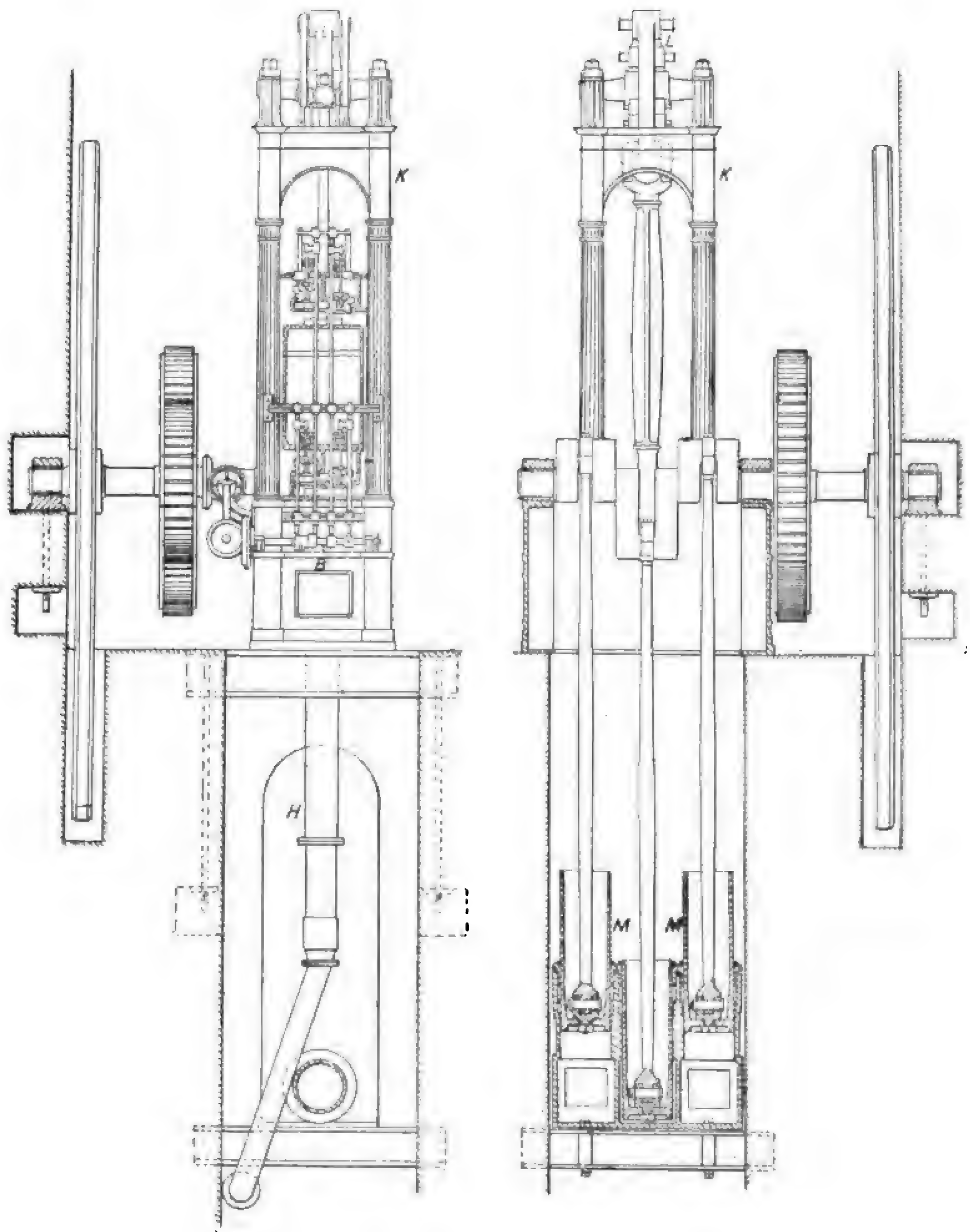


Fig. 85.—Beam Engine. (End Elevations and Sections.)

The cylinder A, is as usual, jacketed; but long D slide valves give place to the double beat valves (of brass) seen in the figures, and short steam passages. As their lift is very small, they are operated from a cam shaft B, which is actuated through bevel gears seen in the end view to the left, Fig. 85, in which also the four tappet rods are seen. The cold water cistern C contains the condenser, and air, and cold water pumps. The condenser D receives the exhaust steam and injection water (the jet apparatus not shown), and the condensed steam and water are drawn thence by the air pump E; the passage, and the foot, and delivery valves being seen in section, and the hot well above. F is the feed pump, and G its suction pipe, the delivery pipe to the boiler being seen at right angles therewith. H is the cold water pump delivering into C.

The general build of these engines comprises the base or bed plate, which in this example consists of cast-iron girders J built into the walls. These support the castings of which the cistern is built, and the fluted columns for the entablature K. The latter carries the bearings for the beam L, whence all the rods are worked. Parallel motion is used for the piston and air pump rods because these are rigid, the others have loose connections. The pumps M M which the engine is designed to operate are worked from a separate crank, driven by mortice gear as shown. They are of the plunger type, actuating flap valves, and an air vessel is inserted.

Beam Micrometer.—To extend the range of the invaluable micrometer caliper, it is fitted to a sliding head mounted on a beam, after the style of the beam caliper, so that dimensions of several inches can be gauged without sacrificing rigidity, or incurring the large bow shape necessary in the micrometer caliper employed for cylindrical pieces. It would be altogether unnecessary to provide the entire length of movement in the micrometer screw, besides introducing difficulties in construction, so this is given a comparatively short travel, usually 1 inch, and its head is set at definite locations of 1 inch apart along the beam.

The upper figure in Fig. 86 shows the Brown & Sharpe type. Here the sliding head A is accurately adjusted upon the beam by the setting block B and its screw, until one of the inch lines upon the beam face and the one on the bevelled portion of the head exactly coincide; the clamping screw beneath is then tightened up. One inch of micrometer screw being available, the head must be shifted to the next line when a new measurement exceeding 1 inch of difference is wanted. The capacity of the instrument is 6 inches in length by 4 inches diameter; another size has double this capacity.

Although it is not found difficult to effect the inch settings by the method of coinciding lines,

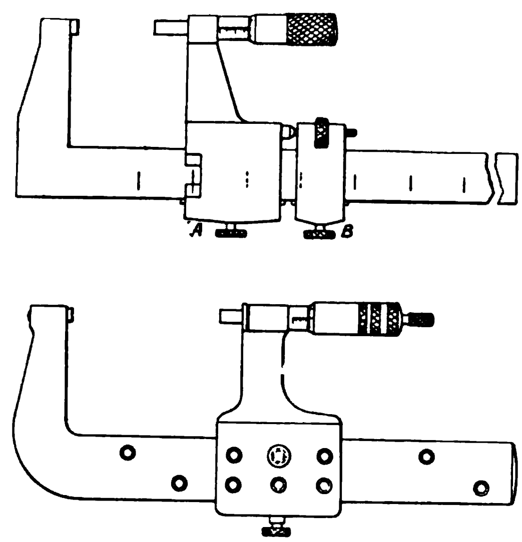


Fig. 86.—Beam Micrometers.

as in this example, yet other devices have been adopted to avoid the use of lines. The Starrett design, shown in the lower part of Fig. 86, employs a plug, fitting into steel bushed holes. There are six of these in both beam and head, each having its particular fellow, through which the tapered locating plug passes. By following this plan, the wear on the plug and holes is divided amongst the lot, and accurate pitching is simplified during manufacture, since for each inch setting, the beam is fixed correctly, and the pair of holes for that particular position lapped out together. The next holes are then taken independently at another fixing, so that lapping once done is not affected by the work

on subsequent holes, which would not be the case if only one hole were provided in the head.

Another type, the Bellows, has a set of pins fitted in the beam, at $\frac{1}{2}$ inch distances, against which a stop on the head rests, and locates at every position.

We will not consider here the details of the micrometers employed, which will be found under the head of **Micrometer**.

Beam Pump.—A type of pump used sometimes for deep well work, in order to avoid the necessity of making a well at the top of the bore hole, as is done when the ordinary vertical connecting rod and vertical barrel are used. In the beam pump the plunger barrel is above ground and is actuated by a horizontal beam driven from the engine. The flywheel shaft on the latter carries a pinion which drives a large spur wheel and crank, whence a connecting rod rocks the beam.

Beams of Uniform Strength.—There is another way of considering the strength of beams besides that of their sectional forms. A moment's consideration will show that by the principle of the lever their longitudinal outlines must needs vary with the methods of support, and of loading, and that taking therefore a beam of rectangular section, the dimensions of its cross-section need not be of the same area at all portions of its length in order to secure uniformity of strength, but proportioned simply to the stresses imposed upon it at its various sections. These theoretical forms of beams of uniform strength, though not followed closely in practice, are nevertheless useful as a guide to the approximate forms. Some of the commonest are shown in Fig. 87.

Two general cases occur. One, that in which the width of a beam is uniform, and the depth is variable; the other where the width is variable and the depth uniform. In the cantilever beam, Fig. 87, A is a beam of uniform breadth b, and variable depth c, loaded at the free end. The curve of the beam for uniform strength is that of a parabola with its vertex at the end a. The curve may be above or below as shown, or both top and bottom edges may be curved, giving the complete parabolic section. The depth of the beam at any section must vary as the square root of the distance of that section from the end a. If the beam is flanged top and bottom, and the strength afforded by the web is neglected, the bottom edge is a straight line,—dotted. If the web is taken into account the form is a compromise between the triangle and the parabolic curve.

If a beam is of constant depth and loaded at the free end, as at B, the sides are straight

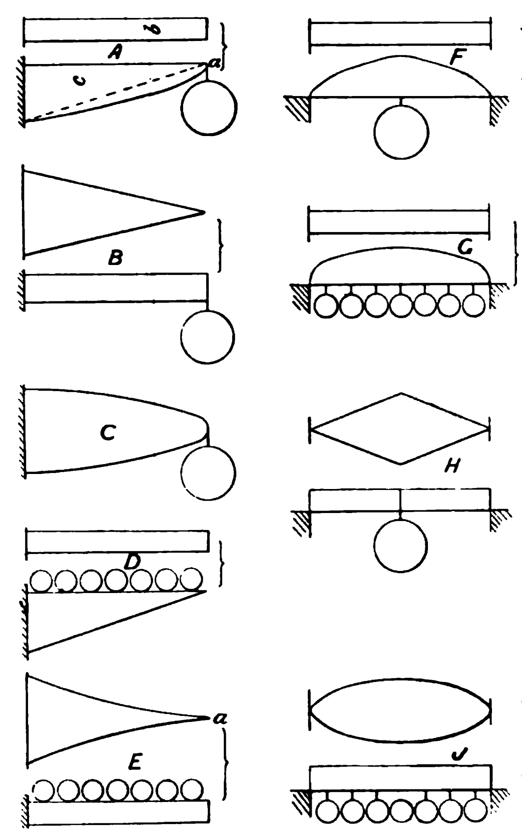


Fig. 87.—Beams of Uniform Strength.

and the form is triangular in plan. If the section of the beam is circular and loaded at the end, as in C, its form is that of a solid parabola. If a beam is of uniform width and uniformly loaded, D, the form is triangular. If of uniform depth and uniformly loaded, E, the sides form parabolic curves, the axes being perpendicular to the centre of the beam, and their vertices meeting at a.

The forms of beams supported at both ends are the duplicates of cantilevers. A beam of uniform width and loaded at the centre has the

outlines of two parabolic curves, F, the vertices being at the points of support. As in the case of A, the curves can be uppermost, lowermost, or symmetrical about the axis. If the width is uniform, and the load distributed, G, the outline is elliptical, the curve coming above or below, or both edges being curved, so forming a complete ellipse. If the depth is uniform and the load in the centre, H, the outline is that of two triangles placed base to base with their apices at the points of support. If the depth is uniform and the load distributed, J, the outline in plan is that of two parabolas with their vertices at the middle, and their bases meeting on the centre line.

Cases occur in which the load is neither concentrated at the centre nor distributed. When it is concentrated elsewhere than at the centre, then the beam can be proportioned for greater strength at the location of the load. If there are two or more points of loading the moments of resistance of the beam can be concentrated correspondingly. The relative strength therefore of every portion of a beam can be proportioned to the relative share which it takes of the load, and the outlines thus obtained, though not always practical or pleasing, would indicate to the eye of the engineer the outlines to which he might approximate with regard alike to economy of material, beauty of outline, and maximum strength.

Beams, Relative Strength of.—The ratio of one beam to another is represented by the formula $\frac{BD^2}{L}$. That is, if we increase or decrease the breadth, B, of a given beam, we increase or decrease its strength in a like ratio. But if we vary the depth, D, the strength varies in direct proportion to the squares of the respective depths. If we alter the length, L, of the beam its carrying power is altered in an inverse proportion. Take for example any beam, and double or treble its breadth, B; its strength is then doubled or trebled. But if we double its depth, D, it is made four times stronger; if we treble its depth we make it nine times stronger; but if we double or treble its length it will be but a half in the first case, or one-third of its former strength in the latter case. Therefore, knowing by testing any bar at what load it will break, then find what proportion or ratio exists between that load and the $\frac{BD^2}{L}$ of the bar, and this gives a constant that will hold good for all bars or beams of the same material, and under the same conditions of loading and support.

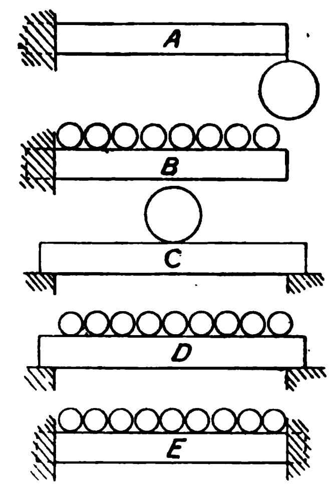


Fig. 88.—Relative Strengths of Beams.

The relative strengths of beams under different conditions of loading and support are as follows, Fig. 88:—

	Relative Strength.
(*A.*) When supported at one end and loaded at the other - -	1
(*B.*) When supported at one end and the load distributed - -	2
(*C.*) When supported at both ends and loaded in the centre - -	4
(*D.*) When supported at both ends and the load distributed - -	8
(*E.*) When fixed at both ends and the load distributed - -	12

Beam Straightening Machine.—*See* **Beam Bending Machine.**

Bean Shot Copper.—Copper which is prepared by pouring the molten metal through a perforated ladle into a vessel of hot water. The result is that the copper assumes the globular form. If cold water is used, feathered shot is obtained which is in the form of flakes.

Bear.—*See* **Punching Bear.**

Bearer.—A common term which denotes

the support of something. It is applied to the top of a lathe bed which carries the heads and rest, and to the bars which carry the ends of the fire-bars of boiler furnaces. *See* **Furnace Bars.** It is not the same thing as a bearing, even though its function is very much the same. The distinction may be generally put thus. The bearer sustains something which has no continual motion, the bearing carries a rotating object.

Bearing Area.—This denotes the area of a bearing on a plane perpendicular to the direction of its pressure. Thus, in a journal bearing, it is equal to diameter × length. The area measured round the circle arc is seldom considered. The intensity of pressure, or pressure per unit area is found by dividing the total load on the bearing by the bearing area. The pressure per unit area varies greatly in different kinds of bearings, and under different classes of lubrication. In a journal bearing it is not uniform over the circumference, but varies from a point of maximum pressure to points of no pressure. The determination of these localities is essential to a proper method of introduction of a lubricant, which should be brought in at the position of least pressure.

The settlement of the suitable intensity of pressure for a given class of bearing, and method of lubrication, is important in order to fix the relative diameter and length of the bearing. In present-day practice bearings are much longer than formerly, with the object of reducing the wear of their surfaces to an almost infinitesimal amount. A good bearing should retain its tooled face unimpaired for a very long period, but this cannot be ensured unless the bearing area is large, in other words unless the pressure per unit area is small.

The determination of the intensity of pressure is a matter of experience and practice, hence it varies considerably even in the same classes of work. The following are selections. For cast-iron journal bearings of factory shafts, 15 lb. per square inch; for railway axles, from 160 to 300 lb. per square inch; for the main journal bearings of steam engines from 400 lb. for fast engines to 600 lb. for slow ones. For pivot bearings 250 lb., for thrust or collar bearings, 50 to 70 lb.

The bearing area of a rivet exercises an important influence on the strength of its joint, inasmuch as the resistance of the plate to crushing under the pull on the rivet should be approximately equal to the shearing strength of the rivet. This is ensured by making the diameter of rivets about twice the thickness of the plate through which they pass. The resistance of the plate is taken as equal to the diameter of the rivet × the thickness of the plate × its crushing strength.

The bearing area of plates held in contact by riveting is usually neglected in calculation. But it must afford very considerable security against slipping under stress when rivets are closed by hydraulic pressure. The larger the number of rivets in a joint, and the wider the seam, the more valuable must be the frictional resistance of the plates to slipping.

Bearing Metals.—The whole philosophy of a suitable bearing metal may be summed up thus: The diminution of friction, heating, and of wear; and when wear does occur, that it shall take place on the bearing, and not on the shaft journal, because it is easier to renew the former than the latter. It would appear as though the quality of metal or alloy in a bearing could be of no importance when perfect liquid friction ensures the absolute separation of the surfaces in contact. The friction only begins when the lubrication is imperfect. As the ideal becomes more common the need for reduction of metallic friction will be lessened. This however must receive attention, for the ordinary commercial mechanisms do not admit of highly elaborated provisions for lubrication.

The conditions which govern the selection of a shaft are different from those of its bearing. Strength, and stiffness are essential in the first; but in the second the main consideration is the resistance which it affords to abrasion, in the absence of a film of oil, and if abrasion occurs that it shall take place in the bearing. The case of soft bearing alloys is met by encasing them in a rigid shell of iron. Another point is resistance to the corrosive effect of certain oils, to which some metals and alloys are more susceptible than others.

The employment of a simple metal for bearings is less common than that of alloys, and is restricted practically to cast iron. This is more

common now than formerly, since the value of increased bearing area has become better understood. Cast iron is very suitable in two conditions, that of large shafts rotating slowly, and that of small shafts rotating at medium speeds. The application of the first occurs in some massive lathe spindles, that of the second in the swivel bearings for shafting. For these purposes an open grain of iron is preferred rather than a close hard variety, because the former retains some lubricant, so affording a glossy greasy surface. When cast iron is used, the intensity of pressure must be kept very low, which is readily done by increasing length, so that the length of such bearings is generally from two to three times their diameter. With sufficient lubrication they endure long service, lasting over many years.

Into the majority of bearings alloys of some kind enter. These are most commonly composed of copper and tin, with or without small quantities of other elements. The standard ideal or type of bearing is that of gun metal, or bronze, in the exact composition of which many specifications are very strict, in insisting on pure mixtures of copper and tin only.

Brass bearings are those in which other elements, chiefly zinc and lead, are added to tin and copper. They are cheaper than those of gun metal, but less durable, and are not considered suitable for high class work.

Phosphor bronze is a valuable alloy largely used, but its composition is variable, and results depend very much on the care with which it is manufactured.

White metals, or antifriction alloys, include a vast number of bearing metals the basis of which is a moderate or small proportion of copper, and large proportions of tin, with antimony, or lead, zinc, or bismuth. Many of these are simply sold as white metals under trade names, or brands without specifying their composition. Their value is generally estimated as that of their capacity to support a certain intensity of stress, far in excess of that which they will have to sustain, or from 4 to 6 tons per square inch. Another point in some antifriction white metals is their ability to resist the action of acids, and soaps, which is the reason why tin and antimony are recommended, these being unaffected by acids in oils. The use of lead is a concession to cheapness, but it also gives a better surface with little or no labour.

The value of the white metals lies in their cheapness, costing less for workmanship than bearings of harder materials. They are often cast around models, and require no further correction. They soon take their bedding by the action of their shaft or spindle, and so make

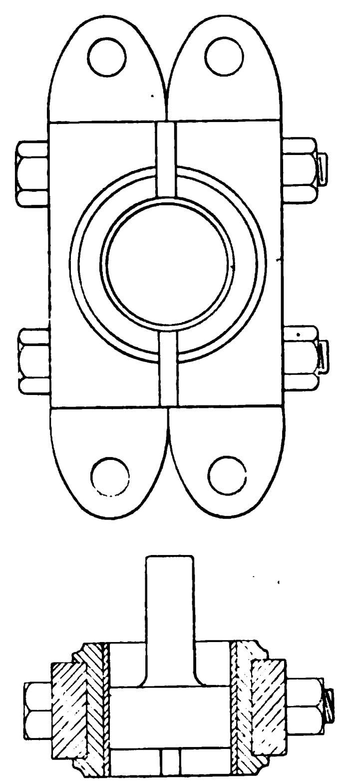


Fig. 89.—Compressing Bearing Metal.

a perfect fit with clearance without further trouble. The softer the alloy, as when lead is added, the more easily is the fit produced, and there is less risk of the shaft being scored than when harder materials are used. If well lubricated they last a long time, and when worn are easily renewed.

Increased durability is often ensured by compressing the metal by means of a mandrel. Fig. 89 illustrates the device adopted by Dewrance & Co. The bearings are turned on

the outside, and held in a chuck, and bored out to within $\frac{1}{100}$th of the finished size. They are then, still held in the chuck, mounted in a hydraulic press, and a mandrel which is smaller than the bore at one end, and of the finished size at the other, is forced through the bearing. A mirror-like surface is thus produced with far less trouble and expense than as though scraping were practised. *See also* **Babbitting**.

Bearings.—There are few details in engineers' work which are subject to so great variations as are those of bearings for axles, shafts, spindles, mandrels, &c. The problem of affording a bearing to a rotating spindle seems simple, yet in practice it becomes extremely complicated.

The three kinds of bearings are the journal, in which the pressure is perpendicular to the axis of the shaft, the pivot or step in which it is parallel to the axis of the shaft, and the thrust, or collar, in which it is parallel with the axis, but taken on the faces of a collar or collars formed round the shaft. The last two will be treated under their proper heads, leaving the subject of journal bearings only for consideration here.

The journal bearings alone number some scores, the proportions and sizes of each of which vary in almost unlimited ways. The rotative speeds of journals exercise much influence on design; the materials used, provision for delaying, and for taking up wear, the lubrication, means of adjustment, and other matters receive much more attention now than they did formerly, and design and construction are much better understood.

At the outset we are met by the fact that the paramount trouble experienced is that due to friction, which causes wear, absorbs power, and produces heating. The amount of power lost in bearing friction is enormous. Fifty per cent. lost in the shafting of a factory is not unusual. It seems singular that while so great efforts are being constantly made to effect economies of 2 or 3 per cent. in engines and power plants that the wastage of journal bearings should be often neglected.

The friction of journals was made the subject of experiment more than twenty years ago by Mr Beauchamp Tower, and the results remain in a better system of lubrication than formerly existed. Up to that period the experiments of General Morin had been accepted as a guide to practice. But those of Mr Tower proved that though Morin's laws were fairly applicable to the condition of a journal up to the point of seizing, they did not cover that of a well lubricated bearing. It was found that instead of the friction being proportional to the pressure, it was almost independent of it. The differences are due to what Mr Tower termed solid, and liquid friction. Thus:—

"The absolute friction, that is, the actual tangential force per square inch of bearing, required to resist the tendency of the brass to go round with the journal, is nearly a constant under all loads, within ordinary working limits. Most certainly it does not increase in direct proportion to the load, as it should do according to the ordinary theory of solid friction. The ordinary theory of solid friction is that it varies in direct proportion to the load; that it is independent of the extent of surface; and that it tends to diminish with an increase of velocity beyond a certain limit. The theory of liquid friction on the other hand, is that it is independent of the pressure per unit of surface, is directly dependent on the extent of surface and increases as the square of velocity. The results of these experiments seem to show that the friction of a perfectly lubricated journal follows the laws of liquid friction much more closely than those of solid friction. They show that under these circumstances the friction is nearly independent of the pressure per square inch, and that it increases with the velocity, though at a rate not nearly so rapid as the square of the velocity."

In a well lubricated journal the surfaces are always separated by a film of oil, which prevents them from ever coming into actual contact. The outcome of this has been a re-designing of bearings, especially of those for high speeds. Automatic lubrication, ring oiling, and other devices, and forced lubrication have been developed enormously, the point at which oil is best applied has been considered, and devices more or less elaborate for regulating the supply have been evolved. The general subject of lubrication will be found treated under suitable headings.

The first broad division of bearings arises out of these facts; that into bearings having sliding friction, and bearings having rolling friction. The first only will be considered in

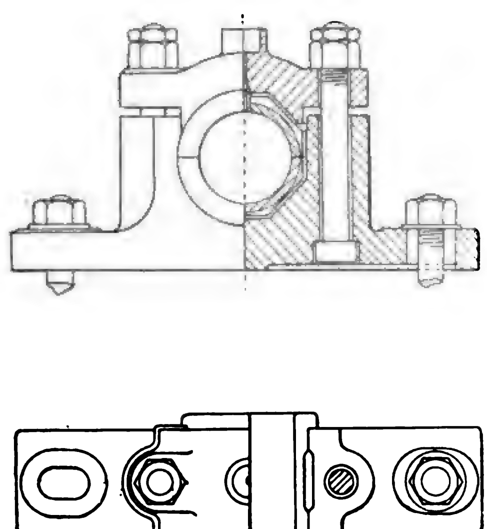


Fig. 90.—Plummer Block with angularly-fitting Brasses.

this article, the second will be found treated under **Ball Bearings**, and **Roller Bearings**.

The simplest type of bearing is the solid one, made by drilling a hole in a block, or boss. This is termed the dead eye, and the bossed bearing. Many of these are employed in the cheaper classes of manufactured goods. They are common on winches and hoists and other mechanisms, where the cost of divided bearings is inconsistent with a cheap product. A reasonable length of service is secured by making them of good length, with or without bushing with brass or gun metal. Besides this, rebushing can be done from time to time as needed.

The desirability of being able to "take up wear" is the reason for the numerous designs of divided bearings, which either have the form of separate portions capable of being closed diametrically by a movement perpendicular to the axis, or by one parallel with the axis. The first is broadly represented by the capped bearing, the second by the bush, bushing, or sleeve.

Capped Bearings.—The commonest type of this class has a cap jointed in the plane of the axis of the bearing, and it is closed in, either by removing a thickness of leather or metal from the joint, or by filing, or shaping the amount required off the joint. The objection to this form is that it is not the most accurate possible, since closing in does not compensate for lateral wear, but only for that in the direction in which the closing is done.

Only therefore in the case of the rougher class of work is wear taken up by closing a cap on a joint going through the diametrical direction. This is suitable for ordinary shaft bearings of cranes, the commoner class of engines, in which a slight clearance is often given, or what is termed a running fit. But it is not accurate enough for the spindles of machine tools, and it is not suitable either for any but parallel necks.

With increase in dimensions it is found better to divide the bearing either into three, or four parts, a method which is frequently adopted in the crank shafts of large engines. In these cases two portions of the bearing are closed by

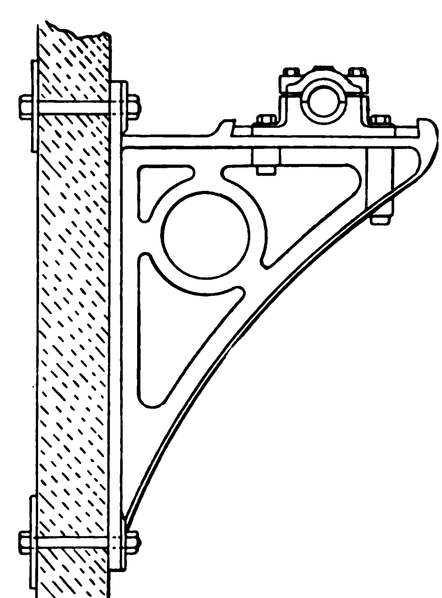


Fig. 91.—Plummer Block on Wall Bracket.

the closing of the cap, and one or two (in the four section bearing) by tapered flanking gibs with tail screws. These engine and pump shaft bearings differ from rigid plummer blocks chiefly

in their greater elaboration of detail, due partly to the practice of dividing the brasses into three or four sections, and in the methods of self-acting lubrication.

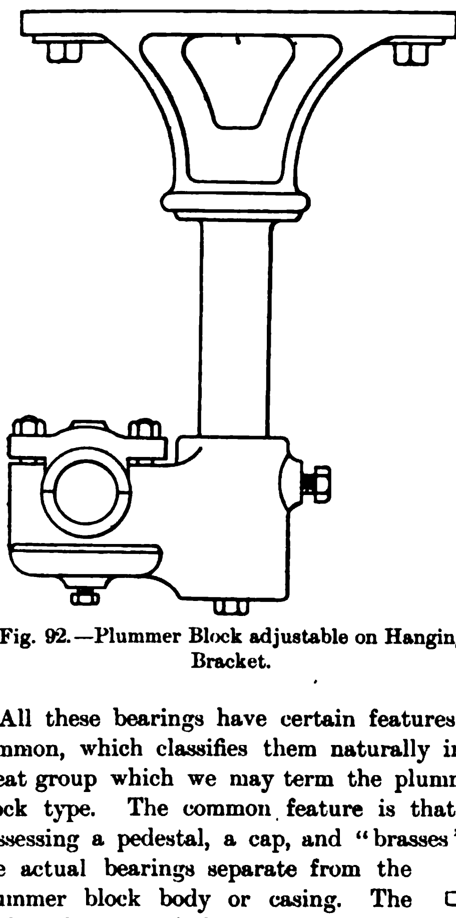


Fig. 92.—Plummer Block adjustable on Hanging Bracket.

All these bearings have certain features in common, which classifies them naturally in a great group which we may term the plummer block type. The common feature is that of possessing a pedestal, a cap, and "brasses"—the actual bearings separate from the plummer block body or casing. The leading features of this group are illustrated in adjacent figures.

The oldest example, Fig. 90, is distinguished by the angular fitting of the brasses. At one time these were generally fitted by hand filing, by red lead contact, and they were not allowed to bear all along, but on chipping strips. The angular facets prevented the brasses from being turned round in their seatings. A fault with nearly all these old bearings was that the length of journal was not long enough, and though speeds of machinery were lower then than now, hot bearings were more frequent.

Turned brasses displaced these, with much economy. To prevent the brasses from rotating, studs are cast on, to fit in holes drilled in plummer block and cap. If the brass has flanges, one stud suffices; if no flanges, two are necessary to prevent endlong movement of the brass. As the brasses cannot be turned around the zone of the stud, a recess is cut in the pattern a little wider than the diameter of the stud.

Around this general design there are numerous differences made in detail. The object often is to reduce the metal, and make as snug and neat a bearing as possible. In special cases mass is desired, and the metal is not lightened but everything is left plain. In ordinary designs the caps do not fit by joint faces, but on the back of the brass only, ensuring full pressure on the latter, and affording allowance for letting down.

These designs are embodied in numerous bearing patterns besides the plummer blocks, as in various brackets, and hang down types, Figs. 91-94, of bearings on sole plates, and in wall boxes.

The increased speeds of shafting have rendered the old proportions of length to diameter, of $1\frac{1}{4}$ to $1\frac{1}{2}$ diameters long insufficient and the practice is to increase the proportion for high speed shafts to from three to four diameters long. Then trouble due to want of alignment arises, in consequence of settlement of bearings, greater wear on some than on others, and poor workmanship. The swivelling bearings invented by

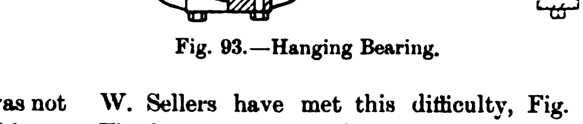


Fig. 93.—Hanging Bearing.

W. Sellers have met this difficulty, Fig. 95. The bearing proper, which is of cast iron, has a spherical enlargement about the centre, that swivels in a corresponding recess in the block

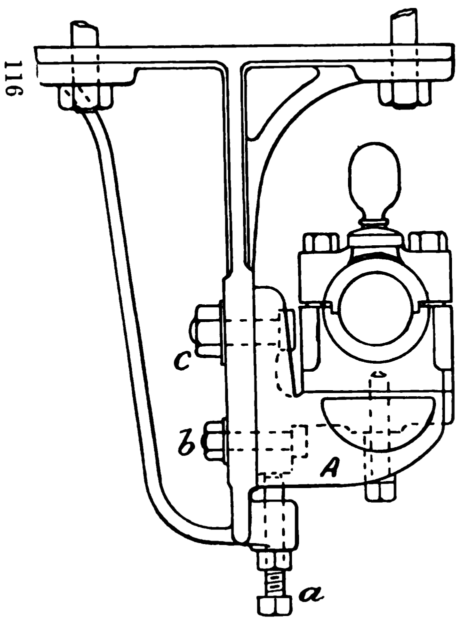


Fig. 94.—Plummer Block adjustable on Bracket A on Hang Down; a, Set Screw, b Clamping Screw; Bearing pivots round c.

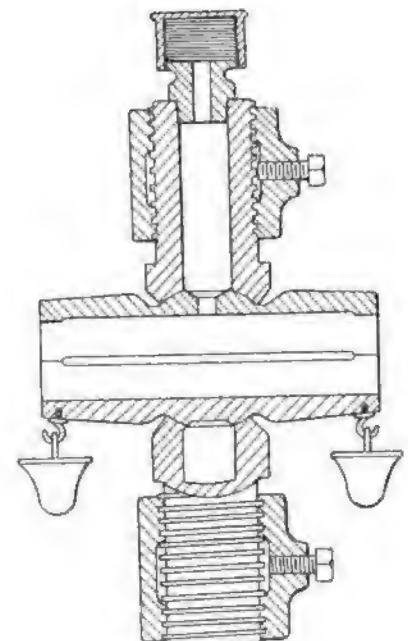


Fig. 96.—Swivelling Bearing.

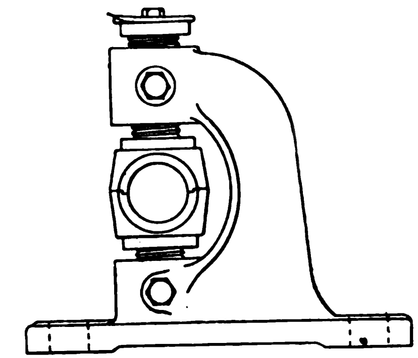


Fig. 97.—Swivel Bearing in Pedestal.

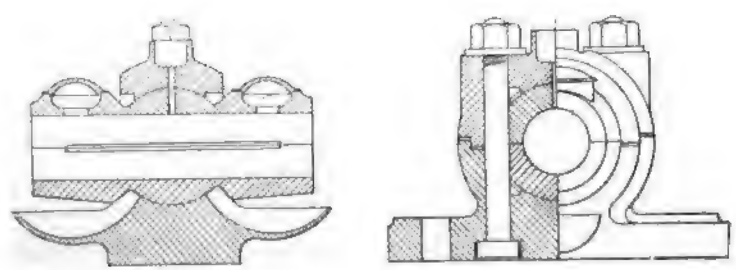


Fig. 95.—Swivelling Bearing.

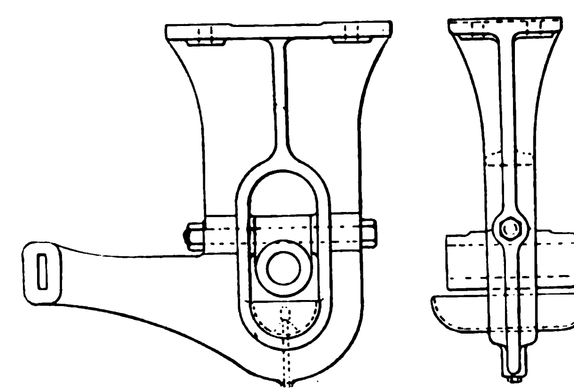


Fig. 98.—Swivel Bearing in Hanger.

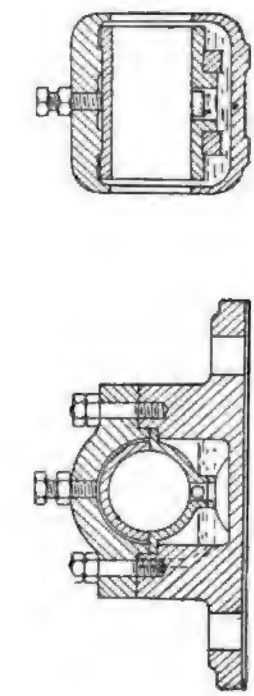


Fig. 102.—Bearing with Roller Lubrication.

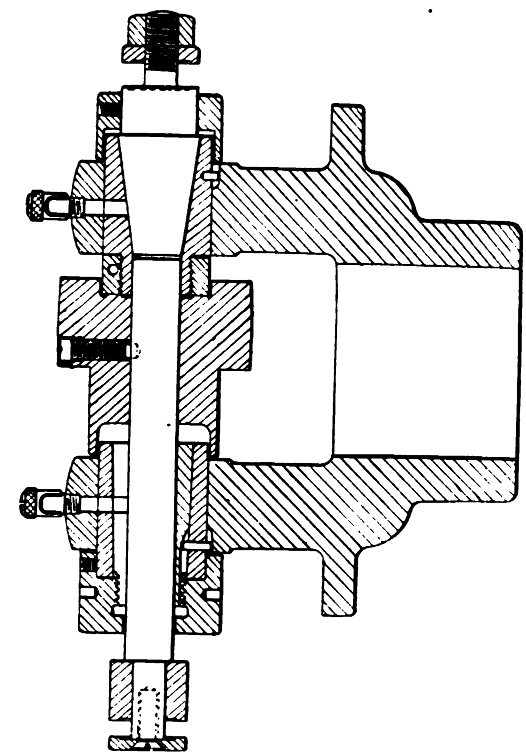


Fig. 103.—Bearings with Endlong Adjustment.

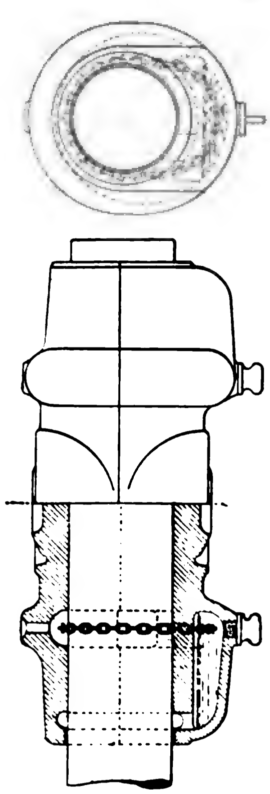


Fig. 99.—Chain Oiling Device.

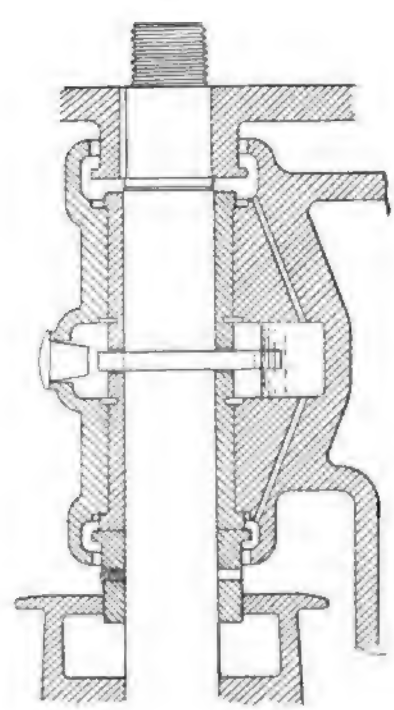


Fig. 100.—Ring Oiling Bearing.

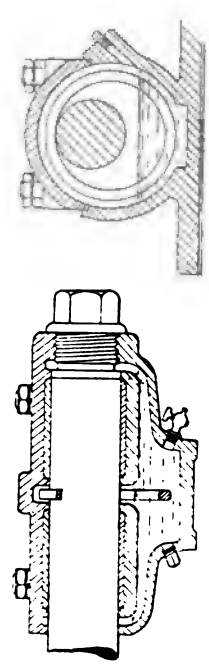


Fig. 101.—Ring Oiling Bearing, Babbitt lined.

and cap, so that the bearing is self-adjusting, following the shaft. To prevent the bearings from rotating, the cap bolts pass down by straight recesses cut in the flanks of the bearings. These are fitted, like the rigid type, to brackets, hangers, and wall boxes. Figs. 96 and 98 show swivel bearings in hangers.

Improved designs also include more adequate provisions for lubrication. Among these are ring, and chain oiling devices, that are embodied in many common high speed bearings, and which being included in some of the examples here given, may be noticed.

Fig. 99 is a chain oiling bearing, Fig. 100 a ring oiling ditto for a grinder. A long babbitt lined bearing, with ring oiling device is also shown in Fig. 101, being that used by the Buffalo Forge Co. for their pressure blowers and exhaust fans, which run at speeds ranging from 1000 to 6000 revolutions per minute. The bearing is between three and four diameters in length, and an oil chamber below is provided large enough to contain a supply of oil sufficient to last from a fortnight to two months, depending on the speed and number of hours during which the blower is run. There are no oil cups, but the supply is received through the opening closed by the plug to the right. Dirty sediment is removed through the cock. The chamber is then rinsed with strong soda water.

In operation the ring, like the chain, carries the oil up from the chamber to the top of the journal, whence it is distributed to the ends, passing to the recesses there, and thence returned to the chamber below. When the oil runs low, the ring begins to rattle, so giving warning of the fact. Fig. 102 is a roller lubricating device.

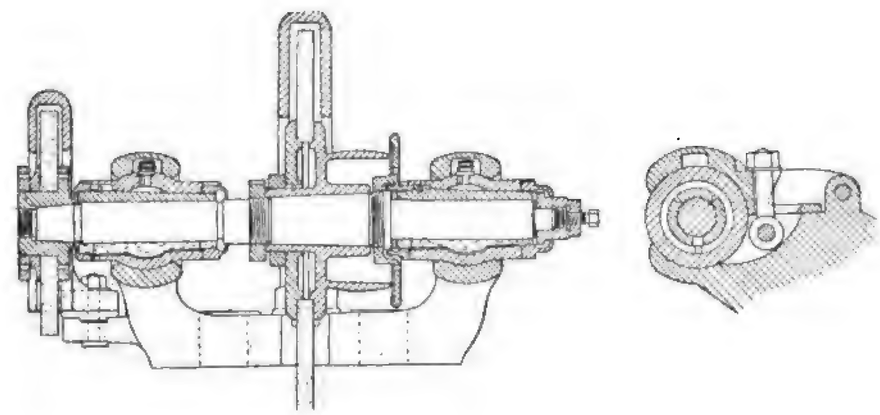


Fig. 104.—Bearings with Endlong and Swivel Adjustments.

The second type of bearing, that in which take-up for wear is effected by a movement parallel with the axis, is employed chiefly in machine tool design, *see* Figs. 103, 104. Here though the details are numerous, the broad principle may be stated thus :—

The bearing is of the split bush type, its external portion is of a conical section, and its ends are prolonged beyond the seating which it takes in the spindle head, to receive nuts by which it is drawn along end wise, and locked. Being rendered elastic (generally by one or more longitudinal divisions, or "splits") its conical bearing in its seating causes it to become closed inwards as it is pulled from the larger to the smaller end of the cone. This is a more accurate and delicate method of adjustment than the one with a cap, because it takes place all round

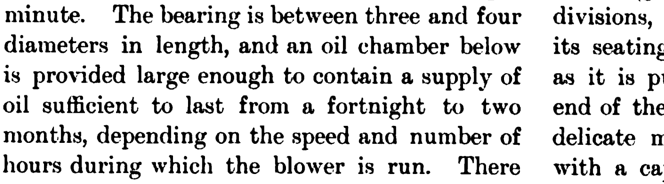


Fig. 105.—Spindle Bearing of great length.

alike. This method of take-up is suitable for the most exacting conditions, not only for turning lathes, drilling and boring spindles, but for milling and grinding machines in which the faintest possible amount of slack would be fatal to the accuracy of results essential to the proper action of these machines.

In a modification of such devices there is the case of spindles which stand out to a considerable distance from their front bearing, Fig. 105, or their lower bearing in the vertical arrangements of drilling and milling machines, or which have to be traversed for feeding purposes through their bearing or bearings. In some of these cases the front bearing is made adjustable to permit it to be kept up reasonably close to the spindle nose, in others, if fixed it is made many diameters in length, as in Fig. 105. In the latter case the length being so great, the provision for take-up is either slight in amount, or is neglected altogether, though these spindles in some cases make several thousands of revolutions per minute.

These remarks do not cover all that is involved in the design of bearings. Others will occur in connection with engines, machines, and motors illustrated in this work. Methods of lubrication are apparent in the illustrations here given, but there are others, some of which will be described under **Lubrication.** Other special forms receive separate treatment under **Axle Bearing, Axle Box, Ball Bearings, Footstep Bearings, Roller Bearings, Thrust Bearings.** *See also* **Babbitting, Bearing Metals.**

The patterns, moulding, and casting of ordinary bearing parts offer no difficulties. They are admirably adapted for plate and machine moulding. In the machine shop they are tooled in sets, the plane faces by planing or milling, and the circular parts by turning, and boring generally. As a rule grinding is not adopted for average work. It is reserved either for a rough class of work, in which case it takes the place of boring, or it is done on precision machines for the highest grades of manufacture. All high class bearings for machine tools are ground, or lapped.

Bearing Springs.—*See* **Springs.**

Beaumontague is a stopping used by pattern-makers, and by wood-workers generally, for filling holes and damaged places. It is generally a mixture of shellac, resin, beeswax, and lemon chrome. These are melted together and thoroughly mixed, and are coloured as required by the addition of suitable tinting matter. It has to be melted for use. This is generally done by holding a piece of it over the place to be filled, and pressing a heated iron against it. It sets hard, does not shrink, and takes stain and polish well. Beaumontague can be purchased ready made in a great variety of colours. Pattern-makers also use chalk, pounded finely, and mixed with varnish, as a filling.

Beaumontague for holes in castings is made, just as cement is for the joints of tank plates. Cast-iron borings 16 parts, sal ammoniac 2 parts, flower of sulphur 1 part; pound and mix, and add 20 parts of borings with water, and a little grindstone dust. Or 20 lb. of borings, 2 oz. flower of sulphur, 1 oz. sal ammoniac, mix dry and add water.

Bed.—Denotes in general a horizontal basis for the building up or fitting of work on, *e.g.*, an engine bed, a pump bed, a cinder bed, a sand bed, a key bed, and so on.

The term, as applied to engine and machine beds, includes many different forms and sections, differing from a **Bed Plate,** in having a considerable proportion of depth to breadth, or area.

Except in the now unusual cases of timber being used for beds, sections are never rectangular, though the bounding outlines generally are. The sections are those of beams or girders of different types, as ⊓, I, ⊏, these being most readily obtainable, and combining rigidity with the most economical distribution of material. For details respecting beds of different kinds, *see* **Beds—Cast; Beds—Plated; Crane Beds, Engine Beds, Lathe Beds.**

Bed Charge.—The bottom charge of coke in a foundry cupola, which is laid in from two to three hours before the blast is put on. It always bears a large proportion to the total quantity of fuel used in a blow. For a four foot cupola it amounts to about half a ton, and in ordinary foundry practice it is nearly or quite half the total amount used in a blow lasting from two to three hours.

In estimating the economy of a cupola, or the "melting ratio," it is essential to include the bed charge in any statement regarding the coke used per ton of metal. It is also necessary to compare the conditions under which different cupolas are run in making estimates of efficiency. Short meltings can never be so economical as lengthy ones. Small cupolas are more wasteful than large ones. Another important point is the degree of melting, whether done thoroughly, or "dead"; or imperfectly. It happens that in the attempt to make a record, foundrymen sometimes melt insufficiently, and produce a large percentage of waster castings. It is better to give an excess of bed charge rather than have it too shallow. It supplies a reserve of fuel which maintains the metal in a "hot" and fluid condition, and really lessens the amount necessary for the upper charges.

Bedding.—A shop term which denotes a good close fit of one piece of mechanism on another. Thus a shaft is said to bed well on its bearing when it shows contact everywhere by the red lead test. This is produced by scraping. A key beds in its key way; such fits as this are assisted by chamfering or rounding the sharp corners of the key, so that they cannot prevent a proper meeting of the broad flat faces. A wooden cog beds on its wheel rim. A moulding box beds on a levelled area of sand. In these and similar senses the term is of constant occurrence.

Bedding in.—Denotes a great section of green sand moulding, which is thus distinguished from the method of **Turning Over**. It means that a pattern is rammed in the mould in the same position in which its casting is poured; that is, the bottom side of the pattern is laid in the bottom of the mould at once, instead of being rammed first with that face uppermost.

It is obvious that when a mould is made by bedding in, there is a disadvantage in the fact that the sand cannot be so readily consolidated as when it is rammed directly in detail on a pattern face, but that it is much more likely to be made too hard, and too soft in different localities, which conditions result in scabbing on the one hand, or in lumpy areas on the other.

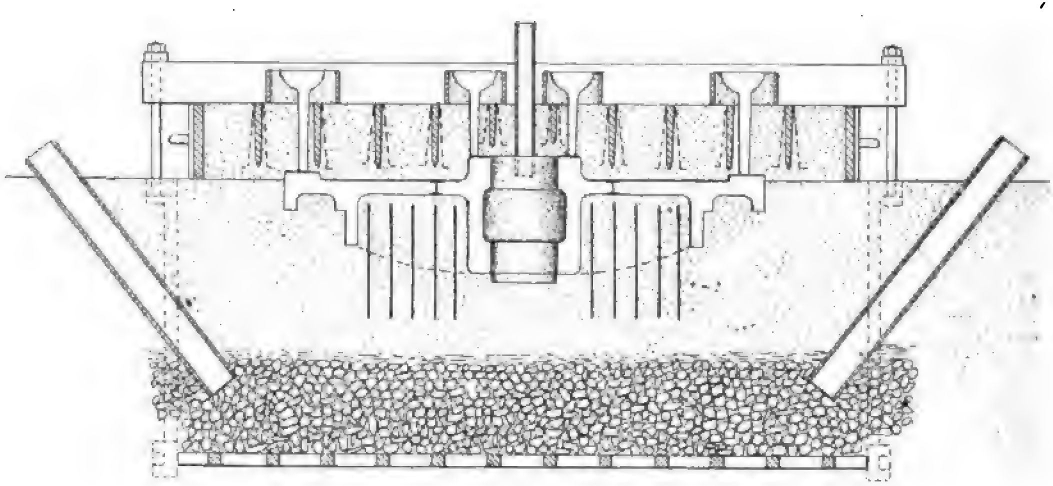


Fig. 106.—Bedding In.

Hence when bedding in is done, precautions are taken as follows:—

If the bed is level or nearly so, that is the most favourable to good results. The bed is rammed all over in detail, much as it would be against a pattern face, its horizontal truth being gauged by parallel strips set in the floor, and tested by a spirit level, and by means of which strips the face of the bed is finally strickled off.

If now the face of the pattern to be bedded in is quite level, it has simply to be laid upon this bed, and the ramming of the sides and top can be proceeded with at once, and no more attention given to the bed. But when projections occur, spaces for these have to be cut out of the bed with the trowel, and the pattern

lightly beaten down to leave its impression there. As the exact amount and shape of the sand removed cannot be accurately gauged, the whole of these impressions have to be gone over in detail with the fingers, removing excess of sand from some parts, and filling in in others, until the pattern beds on an area equally consolidated; *i.e.*, neither too hard nor too soft.

When, as often happens, the face of the pattern is very irregular, the levelling of a bed would be of no service. Then a hole is dug in the floor, and the pattern pushed down therein to leave just a rude outline of its shape, which outline becomes a guide for ramming the sand over the areas to be covered by the pattern. The latter is put in again, and beaten down with a wooden mallet, and its top face checked with a level, and then removed to permit of the process of detailed ramming, and making the softer places firm, being gone over again. This operation may have to be repeated two, three, or four times before the bed is finally suitable for receiving the pressure of the metal. Afterwards the ramming of the pattern proceeds as in ordinary cases.

An important point in bedding in is the method of venting. As there is no bottom box, the principal vents have to be taken down into the sand below, and conducted away somewhere outside of the mould at the floor level. In such cases the accumulation of a large body of gas in the sand below would cause an explosion to occur, or else the gas would not get away in sufficient volume, and the portions remaining in the mould would cause blow holes. The gas is conducted into a **Cinder Bed**, or coke bed, a foot or more below the bed, whence it is conducted away through vent pipes brought out diagonally beyond the edges of the top box, Fig. 106.

The top part box is set in position on the mould by means of stakes, as there are no bottom lugs available. The box is guided either by square strips specially cast on its sides, or by the edges of its lugs.

In the absence of the lugs of a bottom box, the top cannot be secured by cottering down. It is therefore loaded simply with cast-iron weights, which for heavy boxes are cast specially, to avoid the necessity for manipulating a large number of small weights. They are conveniently made in half-ton units, which renders estimation easy of the total number required for a given mould.

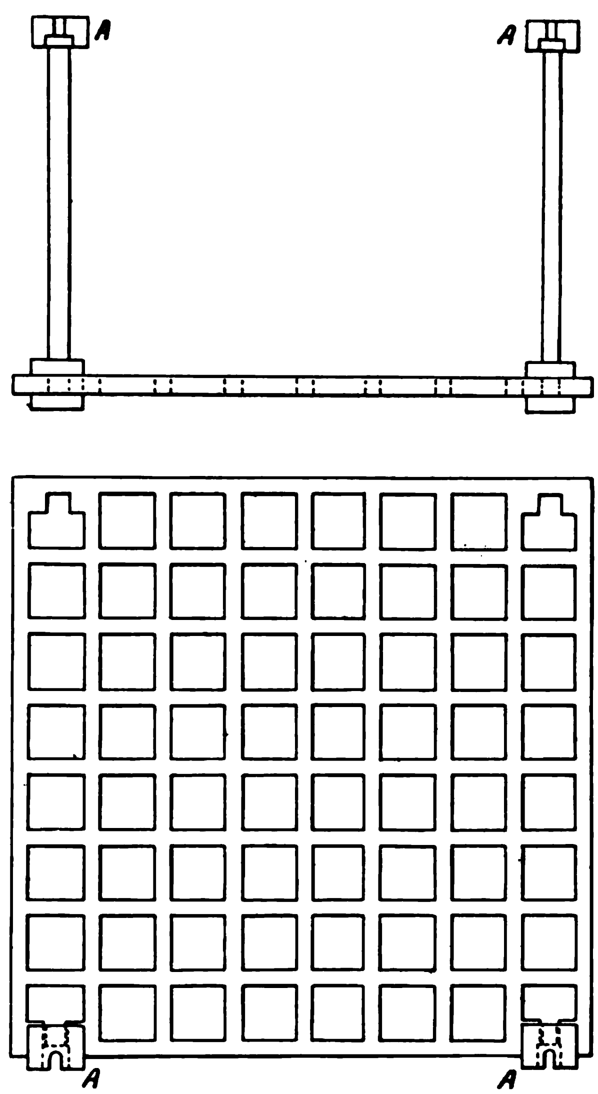


Fig. 107.—Permanent Frame for Bedding In.

When large numbers of the same castings nearly alike in area are required, a permanent fixing is laid down with advantage, by which

the use of weights may be avoided. It comprises a heavy cast-iron frame with four uprights. The heads of the latter are slotted, Fig. 107 A, to receive bolts for the box lugs. Fig. 106 illustrates a bedded-in mould, and Fig. 107 is the frame just mentioned with two uprights, A, in place.

The utilities of bedding in lie chiefly in massive work, the box parts for which would be too large to be conveniently turned over. This however is partly a question of lifting tackle available. In the older, badly equipped shops, more bedding in was done than now when better facilities exist for turning over. Still, speaking generally, the work of bedding in finds its suitable place in heavy work. It is also employed when shapes are awkward, involving very deep lifts, which could not conveniently be enclosed in boxes, and when drawback plates are necessary, which again when large can be more readily fitted in the floor than in box parts. Bedding in is also adopted for moulds made in open sand, but this is only a small section of the moulder's work, being reserved chiefly for foundry appliances, as core plates, back plates, &c. *See* **Open Sand Moulding**.

Bed Plate, or **Base Plate**.—This signifies strictly a plate, the thickness of which bears but a slight proportion to area, and is thus distinguished from a **Bed**, though the terms are often employed loosely to signify either object.

A bed plate has little strength or rigidity in itself, and is therefore backed up with something on which it rests, as timber, concrete, or masonry. Unless properly bedded it is liable to fracture if of cast iron, or to bend if of steel plate. Generally bed plates are cast for convenience of having lugs, joggles, bosses, and other fittings cast with them. Their principal utility lies in carrying bearings, or plummer blocks for gears. In such cases all the bearings for a system of gears may be carried on one large plate, or on two or more plates, separated by considerable distances.

Beds—Cast.—Beds are invariably cast for some classes of work, notably lathes, but in others casting is alternative to plating. The objections to cast beds are some risk of fracture, and of their curving in cooling, more probable with some sections than others. The advantages are that lugs, bosses, bearings, facings, &c., can be cast on in place. It is not necessary to discuss the attachments cast on beds, as these seldom give trouble. The methods of producing the main sections are of chief importance. The easiest section to cast is that shown at A, Fig. 108. Coring is not necessary, because by leaving the bottom flange loosely dowelled the pattern will deliver itself. The mould is shown in section A, Fig. 109, by which it is seen that the sand between the horizontal flanges is carried on grids, or drawback plates. The outer plates may be separate, in the form of drawbacks jointed at the ends. Or a continuous ring grid may be used. The inner plate carries the sand to right and left. The top flange and vertical web are lifted first, then the plates, the removal of which leaves the bottom flange exposed for withdrawal. If the flanges are of the same width and thickness, and the mould is left covered until cold, no curving of the casting will occur. Such a form of bed however is not a popular one, because it has too gaunt an appearance. Neater forms are those shown at B and C, Fig. 108, but they have to be cored (though B may, if broad and shallow, deliver from a pattern) and they are both liable to curve in cooling. *See* **Castings—Curving of**. The plated face is the one that will go convex, and therefore the pattern must be curved or cambered in the opposite direction, or made concave on that face, to produce a straight bed.

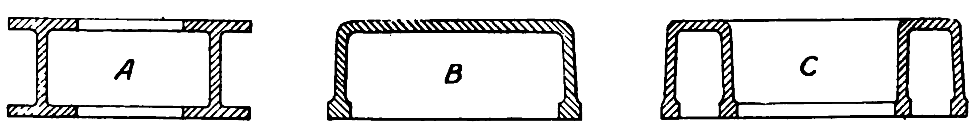


Fig. 108.—Typical Sections of Cast Beds.

But for the casting of the internal and external fillets, the curving would be greater in amount than it is. It usually ranges in beds of these forms, of average proportions, between $\frac{3}{8}$ inch and $\frac{3}{4}$ inch on the total length. The fillets primarily serve the purpose of stiffening

the vertical webs, enabling them better to resist tensile stresses. Such beds are moulded with the top, or plain face downwards, and the cores are hung in the top. Fig. 109 shows pattern C, core box, and mould, in section for the bed C, in Fig. 108. The drawings are self explanatory.

Beds—Plated.—Beds are plated preferably to being cast, for the following reasons:—First, to lessen risk of fracture when beds are subjected to severe stresses, especially when they have to be sent to foreign countries. Second, for convenience of transport abroad, because a built-up bed can be readily taken apart and sent away in smaller and lighter portions. Third, because smaller and lighter sections can be adopted in plated than in cast work, and this is a point of importance in beds of portable machines. Fourth, because there is no trouble with the shrinkage stresses, or cambering, or blow holes, or other faults incidental to castings, and this is therefore in harmony with the present tendency of the displacement of work in cast iron by that in mild steel, where practicable.

The simplest kind of plated bed is that in which rolled joists and channels are employed. This must be classed with plating, because it is done in that department, though plates do not enter into these constructions. The advantage of using these sections is that they are ready rolled to suitable forms, and only require to be cut off, fitted, and united with angles at the abutting portions. The I and [sections are therefore used most extensively in cases where a plain bed is wanted without many extraneous attachments, as bosses, or bearings. And even if these attachments are of large dimensions, they can be made as castings, and bolted on. The economical limit comes when they are numerous and scattered, involving too much separate fitting.

As beds increase in dimensions, the use of rolled sections is not desirable, because the weight increases rapidly. That is, the moments of the sections to resist their diverse stresses are better obtained by building up with plates and angles, or plates and tees than by using rolled joists, or channels. The reason of this is illustrated in the article **Moment of Inertia**. With rolled joists and channels, the vertical web section becomes too heavy near the neutral axis, and the sections adjacent to the flanges require to be heavier. So that by building up, sections can be better proportioned to stresses, and lightness secured with maximum strength.

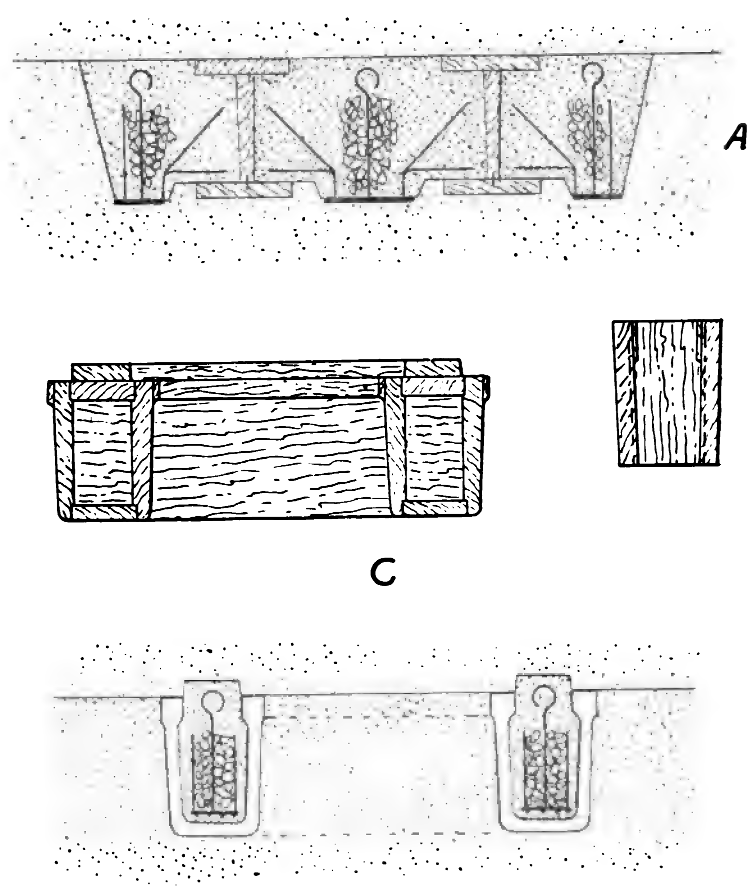


Fig. 109.—Pattern and Moulds for Cast Beds.

Building up is done by the method common to plating. The various portions are straightened first. Joints are sawn, or planed in the best work, rivet holes are either drilled, or punched and reamered. In all but shallow beds vertical stiffeners are employed.

Beehive Oven.—*See* **Coke Ovens.**

Beeswax.—Used in pattern work for imparting a glossy surface to iron patterns, and preventing them from rusting. The pattern is warmed, and a lump of wax taken and rubbed over the surface.

Bell.—The unit of design in a bell is the thickness where it is struck by the clapper, termed the sound bow, or the prim. The latter term relates to the proportions, a prim being the thickness at the sound bow, and equal to fifteen diameters, taken at the bell's mouth. This diameter, so divided also serves as a standard of measurement for all the other dimensions of the bell, diameters, heights and radii being taken in prims. The generally approved main dimensions of bells are: height 12 prims, diameter at the top $7\frac{1}{2}$ prims, weight of clapper $\frac{1}{40}$th that of the bell.

The tone of a bell is of chief importance, because tune is altered readily by turning the casting cautiously, and testing the sound from time to time by the aid of a tuning fork. If a peal of bells is made of the same material and of similar sections, their proportions must be as follows to sound the eight notes of the scale—60, $53\frac{1}{3}$, 48, 45, 40, 36, 32, 30, which are in inverse proportions to the times of vibration of the eight notes. The weights of bells of similar tones vary as the cubes of their diameters, or nearly as follows:—216, 152, 110, 91, 64, 46, 33, 27.

The upper part of a blast furnace is termed the bell.

Bell Casting.—Small bells are moulded from metal patterns, but those of medium and small size are swept up in loam, and generally cast with the mouth downwards, and in the pit.

If made in green sand, a three-parted box is used, jointed at the edge of the mouth, and of the crown. The bell body must be plain outside to deliver; that is, moulded belts must be avoided, and any lettering must be stamped in the mould, or inserted in a rammed core.

The bell may be cast with the mouth upwards or downwards. The latter is simpler, because in the other case the core which forms the interior has to be hung on the top. This does not mean that a separate core is used, but that a grid hung from the top carries the sand rammed on the interior of the bell. This may be rammed in core sand and dried before casting, which is safer than using green sand. The objection to green sand for any but the smallest bells is the risk of lumpiness and distortion occurring when the metal is poured. The remedy is even ramming, and metal not too hot.

Pouring is done either at bottom or top. If a mould is poured mouth downwards, and the gates are brought in at the bottom, there is just a risk that they may break off into the metal. Hence sufficient area is obtained by making them broad but thin, and by casting a ring of gates or "sprays," so letting the metal enter in small volumes at intervals all round. A safer way is to pour around the crown or cap, also with a ring of gates.

The details of green, or dried sand mouldings are those of ordinary turning over. The pattern is laid on a bottom board, and the box parts rammed round and over in succession, the sequence varying according to whether mouth or cap are to be poured downwards.

The methods of sweeping in loam are substantially those of ordinary loam work. The mould is made with the mouth of the bell downwards. The striking bar, centred in a socket just below the floor, has the core board attached to it. The core is swept up over bricks built on a cast-iron plate, with the usual lugs, roughly to the shape of the interior, leaving say about an inch for loam, the final coat being finely sieved. This is dried, and parting material dusted on to receive the loam "thickness" swept with another board. This thickness corresponds with the metal in the bell, and its outside is of course of the same shape and dimensions as the outside of the bell. Over this, when dried, and dusted with parting sand, or sifted ashes, the cope is built, also of loam, daubed on to a thickness of several inches, and carried on a plate with lugs to bolt to the core plate. Care has to be exercised in building this, as it has to be daubed directly on the out-

side of the thickness. The first application is fine, and applied where necessary with a brush, as to the faces of ornaments or letters. Plenty of plasterer's hair is used in the outer layer, and horse manure, or hemp ropes, as binding material. Letterings or designs must be laid directly on the outside of the thickness with tallow or wax, which can be melted off, leaving their attachments to come away with the cope. The crown is built in as a pattern after the removal of the striking bar. The cope is removed and dried, the "thickness" removed, the runners cut, the mould put together in the pit, and rammed round with sand ready for pouring.

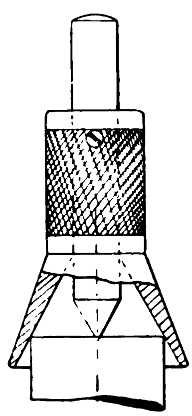


Fig. 110.—Bell Centre-Punch.

Bell Centre-Punch.—This is a useful tool for the rapid centring of pieces to be mounted on centres in lathes, or other machines. It consists of a conical or bell shape casing within which a round punch slides, and is prevented from falling out by a set screw, Fig. 110. The bell being placed on the end of the work, centres the punch instantly and one or two hammer blows are delivered to mark the centre, the impression being subsequently deepened with an ordinary punch, or drilled. The cone of the bell provides for a varying range of diameters. The outside parallel portion of the body is knurled to afford a good grip to the fingers. The work may be circular, or of any regular geometrical shape.

Bell Chuck, or Cup Chuck.—Previous to the advent of the many types of self-centring chucks, the bell chuck was one of the most important of the turner's appliances, but it has been considerably ousted by the superior types mentioned. It has the merit of simplicity and cheapness, comprising simply a cupped casting, Fig. 111, carrying eight set screws, which are adjusted to grip a piece of work placed within the cup. Its advantages are that rough pieces can either be centred, or held eccentrically, as desired, and that a better grip can be obtained on a piece of moderate length which has to be bored, than is afforded by the jaw chuck, which has a bearing of less length than the distance between the bell chuck screws. The disadvantages are that the screws sticking out are a source of danger to the turner, and that when concentric running of work is wanted, this necessitates a good many adjustments of the screws, and trial rotations before truth is attained; a self-centring chuck would save all this waste of time, and grip the piece truly at once.

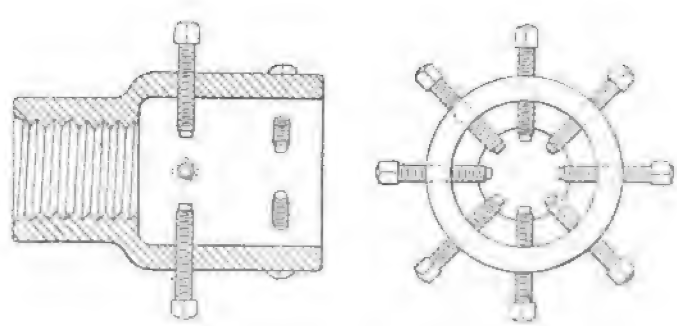


Fig. 111.—Bell Chuck.

Bell Crank Lever.—A lever having two arms which are at right angles with the fulcrum, used for changing direction of motion. *See* **Levers.**

Bell Metal.—This is composed of 80 parts of copper to 20 tin, or 78 copper 22 tin, subject to many variations, including small admixtures of tin and lead. The attempts which have been made to substitute other cheaper alloys have not been successful because the correct tones are not produced.

Belleville Boiler.—This boiler, around which so much controversy has arisen, is the oldest successful water-tube boiler in existence, its history dating back more than forty years. It has been employed on land and sea to a larger extent than any other. Because it requires skilled attendance, the training for which has often been neglected, it has suffered somewhat by comparison with its rivals.

The Belleville belongs to that group designed for ordinary, as distinguished from Express ser-

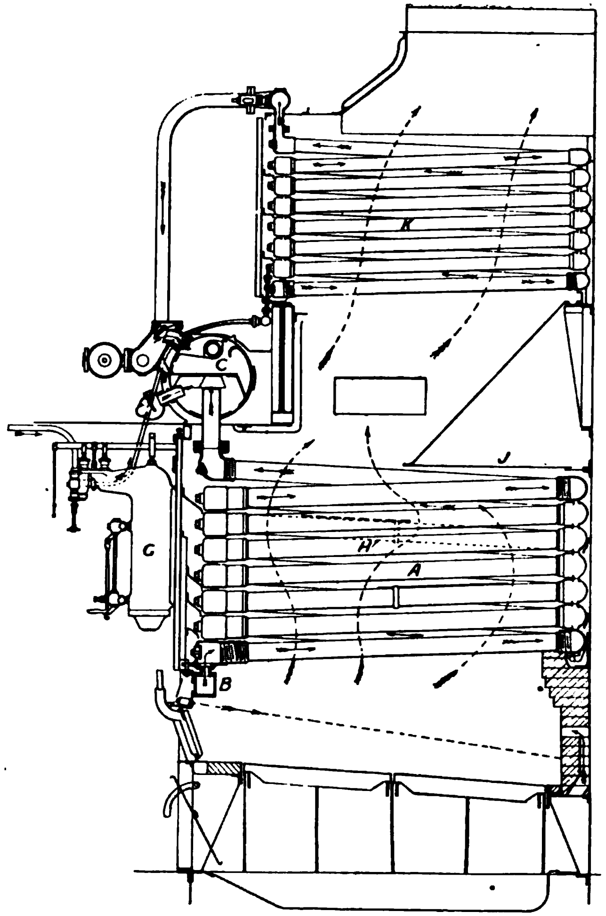


Fig. 112.—Longitudinal Section.

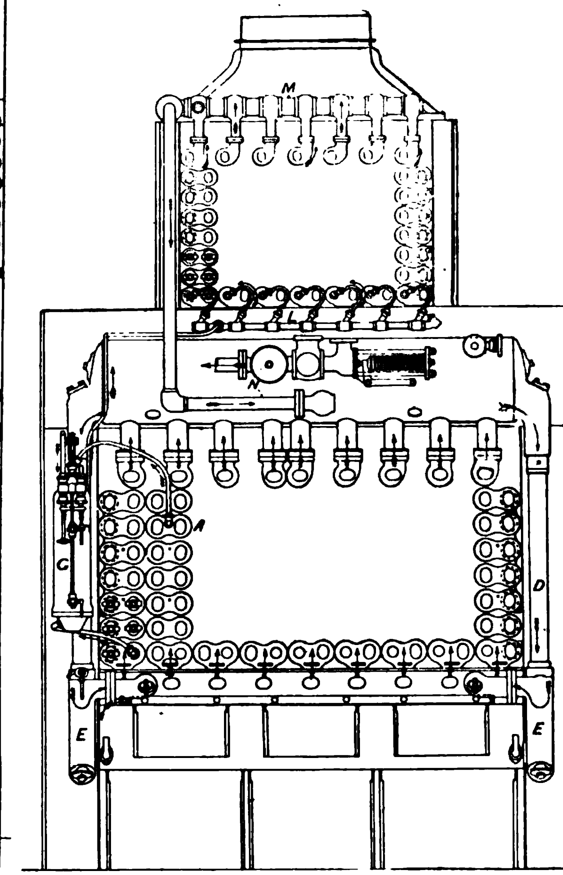


Fig. 113.—Front View.

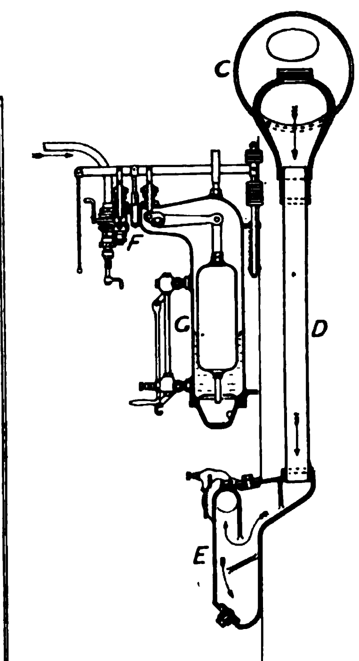


Fig. 114.—Gauge, and Automatic Feed Regulator.

BELLEVILLE BOILER WITH ECONOMISER.

REFERENCES TO FIGS. 112-114.

A. Steam generators. *B*. Feed collector. *C*. Steam and feed separator. *D*. Return water pipe from separator to ejectors *E*. *E*. Ejectors, or mud holes. *F*. Regulating taps of feed water pipes. *G*. Gauge and automatic regulator for feed water. *H*. Movable partitions, or bafflers. *J*. Bafflers at sides. *K*. Economiser tubes. *L*. Cold-water collector for economiser tubes. *M*. Hot-water collector for economiser tubes. *N*. Steam valve for main engines.

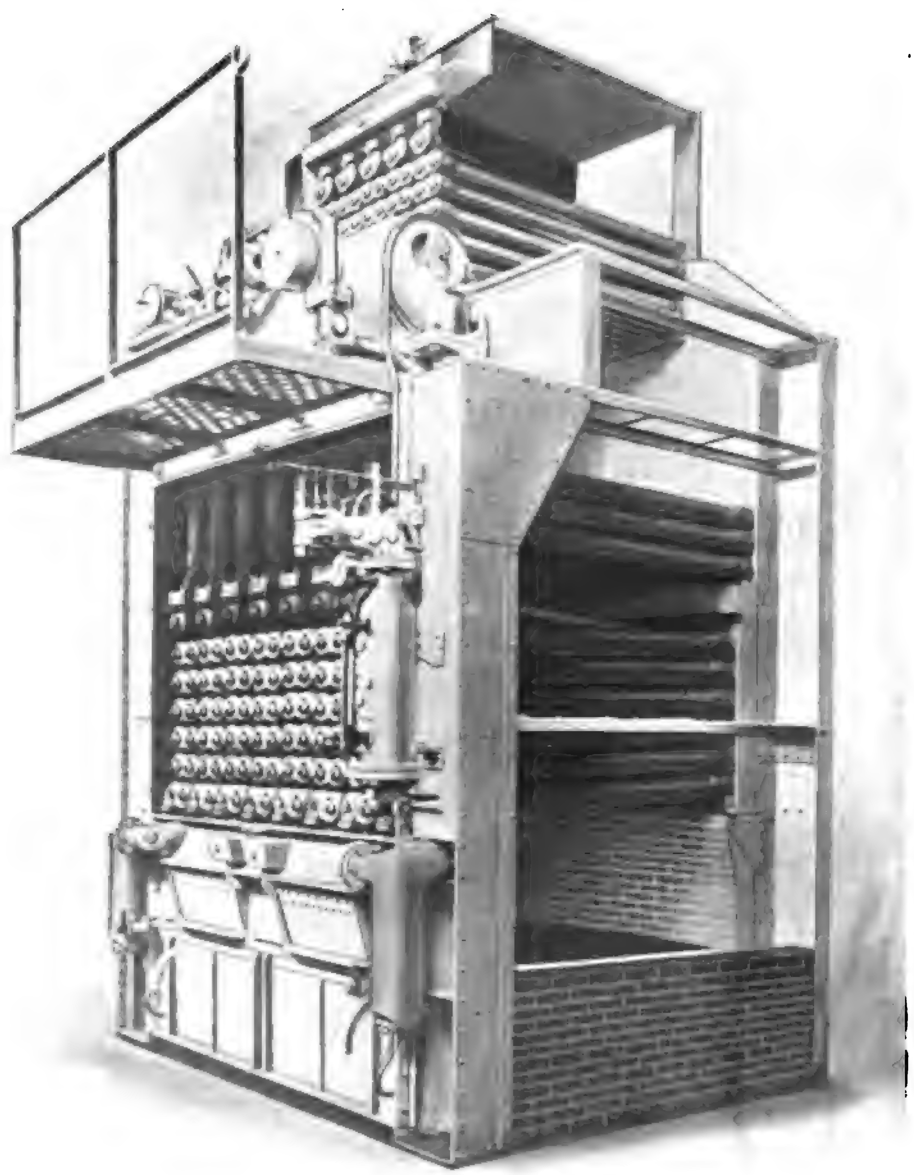


Fig. 115.—Belleville Boiler with Economiser.

To face page 126.

vice. Its main features, Figs. 112-114, and Fig. 115 (Plate III.), are the nearly horizontal position of its tubes, their arrangement in elements, and delivery direct into the steam separator. The tubes A are arranged in a zigzag fashion, each being jointed to its fellows at the ends by means of junction boxes. An element comprises seven tubes sloping in one direction, and seven in the opposite, united by the boxes just named, and a boiler comprises from seven to nine of such elements. The steam has to pursue a zigzag course therefore from the lower to the higher tubes, before it escapes into the separator. The water is distributed to the several elements by a feed collector B of rectangular section in connection with the bottom junction boxes, and the steam delivers through top junction boxes into the reservoir in which the water and steam are separated, by means of baffles—seen in the cross-section of the separator, C, Fig. 112. On each side of the boiler there is a downtake D formed by a large vertical tube which connects to the feed water collector.

An early difficulty with the Belleville was that the hot gases got away too quickly from among the tubes. Two important additions were therefore made, baffle plates in the form of horizontal screens among the tubes, and an economiser K above them, both shown in the illustration. The economiser utilises some of the escaping heat, and it heats the feed water. A disadvantage of the latter in Navy boilers is the resulting increase in height.

Bellied.—A shop term which denotes **Camber**, or **Cambering**.

Bellied Core.—A **Chambered Core**.

Bellied File.—A file which has the largest amount of convexity lengthwise. *See* **Files.**

Bellied Girder.—A girder having convexity or bow on its length.

Bell Mouth.—A trumpet-like form, which is adopted in water and other mouthpieces. *See also* **Adjutage**. Such a section is also termed Bell-mouthing.

Bellows.—*See* **Smith's Forge**.

Belly Helve.—Denotes that particular form of helve or lift hammer used by puddlers, in which the cam block is situated about midway between the hammer head and the fulcrum. In the other form of helve,—the nose, frontal, or head-lift type, the hammer head is placed between the lifting cam and the fulcrum. The advantage of the belly helve is that the anvil is unobstructed on three sides, while in the nose type it is only open on two opposite sides.

Belt Clamps.—Generally a belt is laced when off its pulleys, and slipped on over the edge by hand, or by a shipper bar or other device. All belts up to 4 or 5 inches in width are so treated, but those of greater width are put on by the aid of clamps, Fig. 116. The ends to be laced are gripped in the clamps,

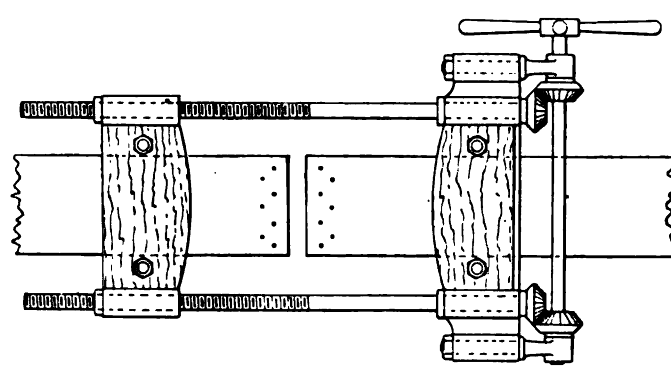


Fig. 116.—Belt Clamps.

which are drawn together with screws, of which there are different designs, and the lacing then done in place. This not only avoids the difficulty of throwing a wide belt on its pulley, but prevents the stretching of one side, which is liable to occur in time when this operation is often repeated, and which results in a crooked belt, and uneven running.

Belt Conveyor.—A type of conveying apparatus in which a broad belt of cotton duck faced with indiarubber transports loose material, by its movement over pulleys. This device is employed in conveying grain in elevators and flour mills, coal, clay, crushed rock, charcoal ashes, tobacco, printers' sheets, and much besides. The power required for transmission is ridiculously small, but the expense of renewing belts is heavy. They cost less for

maintenance than other systems, besides which they run noiselessly.

In the earlier belt conveyors, the belts generally ran flat over flat rollers, but the material was liable to roll off. At present belts are supported at their edges by means of flanking pulleys, at an angle of 45°, which turn up the belt in trough-like fashion. These have been evolved from the idlers, one kind being rigid boards flanking the course, another conical side idlers, to both of which there are great objections, due to the rapid wear of the belts at the turned-up portions. The empty belt is supported on its return by pulleys beneath, which are either plain and continuous, or two in line. Guide pulleys are often fitted at the sides to prevent the belt from side sway.

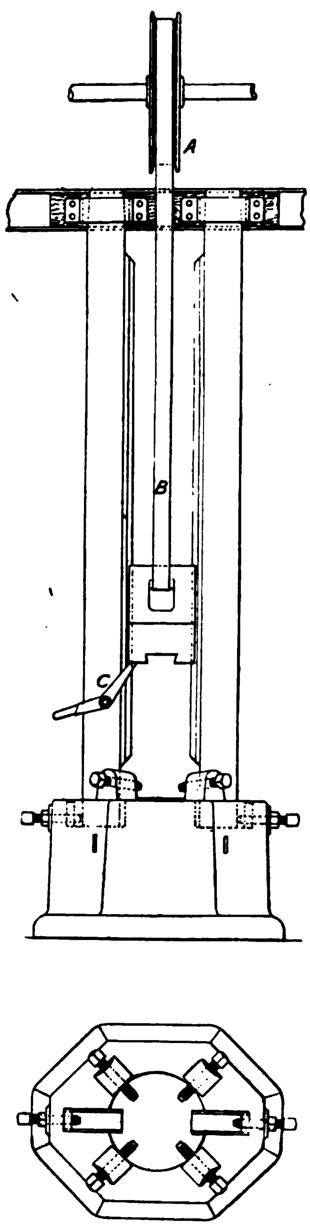


Fig. 117.—Belt Drop Hammer.

The widths of belting in common use are 22, 24, and 26 inches. The average speed is 300 feet per minute, but speeds of from 450 to 650 are not excessive. The belts are of four, five, and six ply. The basis is cotton; the thickness of the rubber covering should depend on the nature of the material. Rubber wears away rapidly under the attrition of the materials dropped on the belt, and more about the central parts than at the edges. Mr Robins recommends a thickness of not less than $\frac{1}{4}$ inch for material weighing over 50 lb. per cubic foot. An important practical point is to deliver the material at approximately the same speed as the belt is travelling at, and not let it fall from a height, which soon ruins the rubber.

Belt Dressing.—*See* **Belting.**

Belt Drop Hammer, or **Kick Stamp.**—A drop hammer which divides favour with the board drop type. It has long been popular for light forging and stamping, recommended by its simplicity of operation. The driving pulley, A, Fig. 117, runs freely, doing nothing until the attendant pulls a handle attached to the free end of the belt B, when the friction between pulley and belt lifts the tup. The release of the handle arrests the action, so that it is under nice control. Limitations of power come in, as about 10 cwt. is the limit at which one man can work sueh a hammer. In Fig. 117 the handle is not seen, being on the other side of the hammer. C is a catch which holds up the tup when not in use. The lug attachments seen below are for gripping stamping dies.

Belt Fastenings.—These often give trouble, hence the reason for the numerous designs of lacing in use, and the large numbers of special fasteners to take the place of lacing.

When belts are built up by the manufacturers, the joints are cemented, and riveted with copper rivets, or laced. This is on a different footing from the jointings which have to be made in the shops. These are of a more or less temporary character, for though a belt is jointed up for a drive, it stretches from time to time, besides which belts are changed on different machines occasionally. Insertions also have to be made, so that the strapper is kept busy.

There are two ways of making joints, one by means of scarfed joints, the other with butts. There are objections to both if badly done. In the first there is the risk that the feather edges of the scarfings are liable to lift up, and

project, causing the belt to jump and flap as it passes round the pulleys. Copper clasps should be used at the edges to prevent this. The butt joint is a weak form, it is not easily laced, and it makes a kink in running round the pulleys.

Laces are of leather, the holes for which are punched with a hollow steel punch, or with an awl. The latter forces the material aside, just as a bradawl does in wood, but a punch cuts the leather, and removes the core, which is the better plan, because the belt is less liable in this case to become torn through the holes. An elliptical punch is preferable to a round one,—the longer axis of the hole running in the direction of the belt.

One difficulty with leather lacings is the bunchy character of the joint. It is difficult to avoid this entirely at first, but it is minimised by lacing tightly, and flattening the lace and joint with a wooden mallet. A better way is to pass the joint a few times through hand rolls.

Several designs of lacings are shown in the group Fig. 118. A shows a common form, the advantage of which is that the parallel portions of the lace run next the pulley faces.

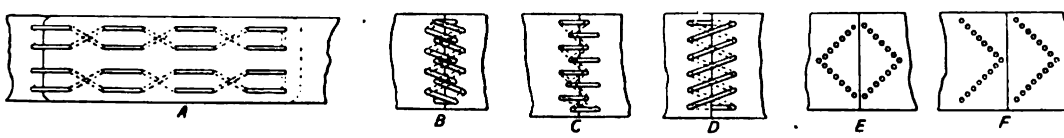


Fig. 118.—Belt Lacings.

B to F show lacings for butt joints. In C the parallel lines of lace go next the pulley. E and F are believed to retain the strength of the belt better, due to two holes only being in line anywhere.

Metal fastenings are employed to a great extent. The oldest, and a perfect type for scarfed joints is the screw fastening, Fig. 119, A. It lies flush with the faces, and becomes polished smoothly by its friction on the pulley. The objection that the edges cut the leather is not a serious one. Jackson's plate fasteners are shown at B, C. D is the yellow metal clip, E is Baxter's lock-nut fastening. A plate clip

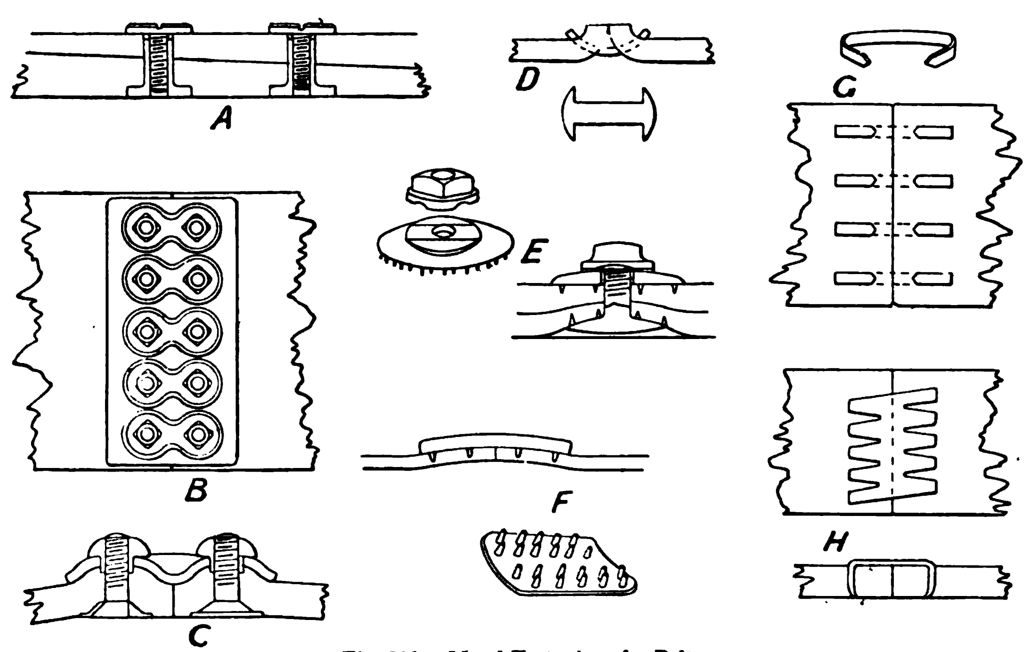


Fig. 119.—Metal Fastenings for Belts.

with prongs is seen at F, soft metal clips are illustrated at G; H is the "Bristol" steel clip. Though the clip is a simple form of fastening for butt joints, its only recommendation is its simplicity. The objection is that it produces an unsafe excrescence. For cotton and canvas belting chiefly, screw fastenings are to be preferred.

The lengths of belts may be obtained trigonometrically. But the best course is to measure the actual length with a tape. An approximate calculation is the following:—Add together the diameters of the pulleys in feet, and multiply the result by 1·6. Adding this to twice the distance from centre to centre of the pulleys gives the approximate length of the belt.

Belt Fork.—*See* **Striking Gear.**

Belting.—Belting is made of leather, camel hair, llama hair, cotton, indiarubber, and gutta-percha. Notwithstanding this wide choice of materials, rope driving enters into rivalry with belting for many functions.

The competition of other varieties however has not displaced leather from its position as the best all-round material for belting. It possesses the greatest endurance, for it will last for a generation in constant service. But to get the best results butt leather must be used, and not the flanks, nor the offal. It must be of homogeneous material, that is the quality of the pieces sewn together to make up the length must be similar, for if otherwise, some sections of the belt will wear more rapidly than others, and when this happens, true running is no longer possible, patching must follow, and thus the evil grows. The spectacle of wabbling belts is common in most factories, the result of unequal wear, and of patching. One point in favour of the woven beltings is that they can be made homogeneous throughout, however long or wide their dimensions may be.

The principal rivals to leather are the Reddaway camel hair belting, and the Gandy cotton belting. These give very excellent results, and many firms use them by preference. Here there is room for differences of opinion. A point in favour of the camel hair belting is that it slips less than leather. In other words, the coefficient of friction between belt and pulley is higher in the former, and higher ratios between the tensions in the two sides of the belting are obtained.

Experience with belting proves that many things affect results, so that abstract considerations weigh but slightly. Those who habitually use one kind of material become sceptical as to the virtues of another kind. Excellent examples of the utilities of each might be cited from the practice of different works. But there are some points which each have in common, and to these chiefly our attention should be devoted. They refer more to the principles and methods of belt driving than to the materials used.

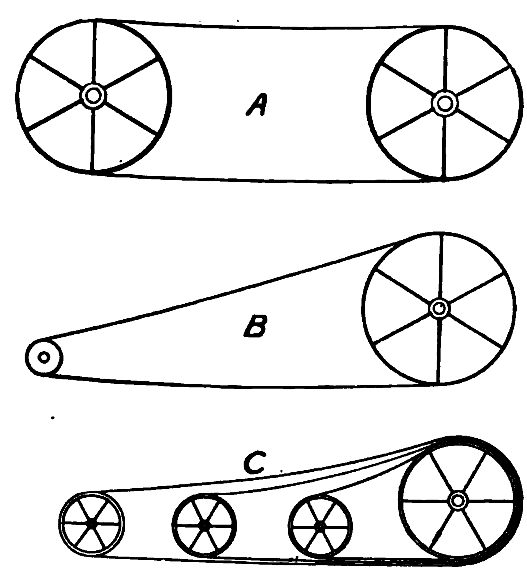


Fig. 120.—Belt Drives.

In the first place any belting shows to best advantage when the distance between pulleys permits the belt to sag well, with the result that severe tightening up is not necessary, and that a good arc of contact is made round the pulleys. Short drives are always more or less inefficient, and they also strain the belts, and wear them rapidly. Horizontal drives, Fig. 120, A, are more effective than vertical, and the efficiency of oblique driving is less than the first named, and greater than the second. It is less in the vertical position, and positions approaching thereto, because the tension is insufficient, in consequence of the absence of sag. It may be increased by using a binder pulley or pulleys,

but this device absorbs power in friction, and moreover wears the belt. The efficiency is less also when pulleys greatly differ in diameter, Fig. 120, B, than when they are nearly of equal size, because a small pulley affords only a small arc of contact. If small pulleys are unavoidable, then it is better to drive with a broad belt than with a narrow thick one, because the outer layers of the latter are more strained in passing round. Slip is also more liable to occur. Going to the other extreme, a very long drive is objectionable, because the belt sways from side to side, and in extreme cases it sags so much that the bottom portion has to be supported on an idler pulley. If very long belts are required, then they should be as light as possible. At high speeds heavy belts cause loss in centrifugal effort.

The limit of slackness is that at which the belt slips. Up to that, the greater the amount of slack the better. This must not be confounded with slip that occurs from such causes as insufficient power, want of alignment in pulleys, or tightly fitting journals. Tightly fitting belts put more work on the journals and bearings, and they absorb excess of power. Heating of bearings is a frequent unsuspected cause of belts slipping off, because of the hard running consequent on this heating throwing too much work upon the belts.

With respect to overstrain, due to running belts beyond their tensile capacities, it is necessary to work with a very low factor of safety, if the period of service is to be prolonged. Up to a certain limit, stretching occurs in new belts, but after this has been taken up once or twice, the belt should go on for many years. But if regularly subjected to overstrain, the stretching will continue until fracture occurs, sometimes repeatedly, and the belt becomes ruined. The less a belt is allowed to stretch the better, because also it creeps more than as if it were not overstrained. A belt will stretch when not in use if left strained on its pulleys; for this reason many belts are thrown off their machines at night, and many loose pulleys are also made of smaller diameter than the fast one adjacent.

In leather belts there is a difference in the two faces. The "flesh" side, or the inner face of the belt is the one that should run next the pulleys. The temptation to run the "grain," or the outer side of the belt arises, because power is gained in that way. But the latter has a shorter life, because it is working against the natural growth of the hide. With the flesh side inwards the belt is more pliable. If the flesh side is dressed with boiled linseed oil it will soon grip as well as the other. The oil oxidises and yields a smooth driving face, slightly gummy.

This leads up to the question of the care of belts. The use of resin, so often practised, to make belts cling to their pulleys is injurious. Boiled linseed oil applied to them twice or three times a year produces a clammy surface due to the oxidation of the oil, which is the condition most favourable to good running. A hard belt becomes polished by the pulleys, and the belt loses its nature and slips, and strains the journal bearings. Currier's dubbing is a good application for belts that run in warm engine rooms. One coat of dubbing, and three of linseed oil once a year is recommended. Castor oil is also good.

The obvious superiority of belts of camel hair, cotton, and llama to leather lies in atmospheres laden with steam, and humidity, and for outdoor work. These conditions are injurious to leather, while the other materials stand them well. But the edges of woven beltings fray out by contact with shifting forks, and flanges. To prevent this, some of these belts have leather edges riveted on.

The question of the best arrangement of belts for transmitting power is differently answered. It may be done for a given speed by increasing thickness, or width, or by duplication. Circumstances must often leave little margin for choice. High speed shifting belts must necessarily often be narrow, in order to save loss of time in running them between their fast and loose pulleys. But in belts that have not to be shifted, increasing the width is generally preferable to increasing the thickness beyond a reasonable degree. But there are often limitations to width when high powers have to be transmitted, either by reason of the difficulty of getting a wide belt, or because the width of pulleys cannot be increased. Here the duplication of belts has answered well; two, three, or

four belts running independently on top of one another, and combining flexibility with increased power. They are not connected in any way. The outer ones run faster than the inner, each doing its own share of the work. One of the advantages of these occurs in short drives, in which if a single belt is used, it must be strained up tightly, but compound belts may be run slack. The gain is not doubled, but ranges from 50 to 80 per cent. per added belt. The drive is varied by combining a link belt with a thinner belt of common leather over it. The

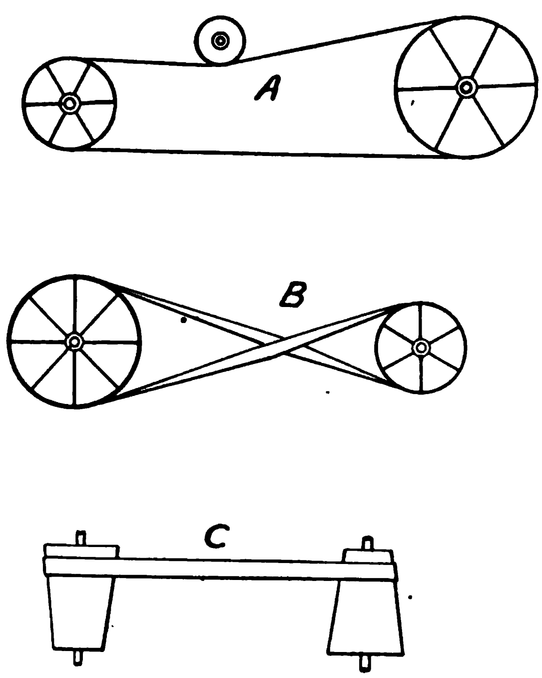


Fig. 121.

A. **Binder pulley used to lessen slip of belting.** *B*. **Crossed belt for driving pulleys in opposite directions.** *C*. **Reverse cones for producing variable speed.**

link belt clings to the crowning of the pulley and the leather belting then follows its curve. Compound drives are also adopted in the case of several pulleys being driven from a single one, Fig. 120, c. Fig. 121 illustrates a binder pulley, a crossed belt, and a variable speed drive.

The direction of driving of belts presents some awkward problems, besides those already remarked on which take place over pulleys having parallel axes. The difficulties do not lie in the proper disposition of the pulleys, but in the punishment inflicted on the belts. The fundamental rule is that the edges of the driving and driven pulleys must come in the same plane, Fig. 122, A. The positions of the leaving edges then are a matter of no concern, but the drive cannot be reversed.

The commonest twisted drive is that of pulleys having shafts at right angles, termed the half-twist drive, B. This is a case where a wide belt is impossible, because the strain on the outside of the twist becomes too severe. Either a narrow belt must be used, or the shafts must be connected with a vertical shaft, and gear wheels. But this is a case where the link belts, tapered in cross-section solve the difficulty. These lie close to the pulleys all across instead of a portion of the belt leaving the pulley. Fig. 122, C is a quarter-twist drive. In other drives guide pulleys fulfil a useful function, some examples of which are shown in the group of Figs. 122.

The value of link belting lies primarily in its flexibility. It clings round the crown of the pulley when made on the flexible centre design, and it permits the escape of the air which is confined between a pulley rim and a solid belt, and which causes slip to occur.

The experiments which have been carried out to ascertain the coefficient of friction of leather belting have been conducted on two broad lines, one being that in which the effect of slip has been neglected, the other in which slip was included. The experiments of M. Morin left slip out of account as an element in the frictional coefficient. In those of Messrs Briggs and Towne, it was not satisfactorily included, the velocity being uniformly 200 feet per minute. Later experiments worked at varying degrees of slip, in one case recorded, down as low as $\frac{3}{8}$ths inch per minute.

General Morin found coefficients of friction to vary between 0·544 and 0·596, the mean being 0·573, but as already remarked no account was taken of slip. The method of experimenting was to suspend the belt over a fixed drum of wood or cast iron, and to attach scale pans to the free ends. In one pan, the weight was constant, in the other the load was gradually increased by added weights until the belt slipped. Dynamometers were also inserted

on both sides of an endless vertical belt which passed round a pulley and an oak drum.

Messrs Briggs and Towne published the results of some experiments on belts in various conditions, being new, partly worn, and weakened by long service. The method adopted was similar to that of Morin, a suspended belt with scale pans, and added weights. The mean of 168 experiments gave a coefficient of 0·58.

The ultimate strength of leather belts of

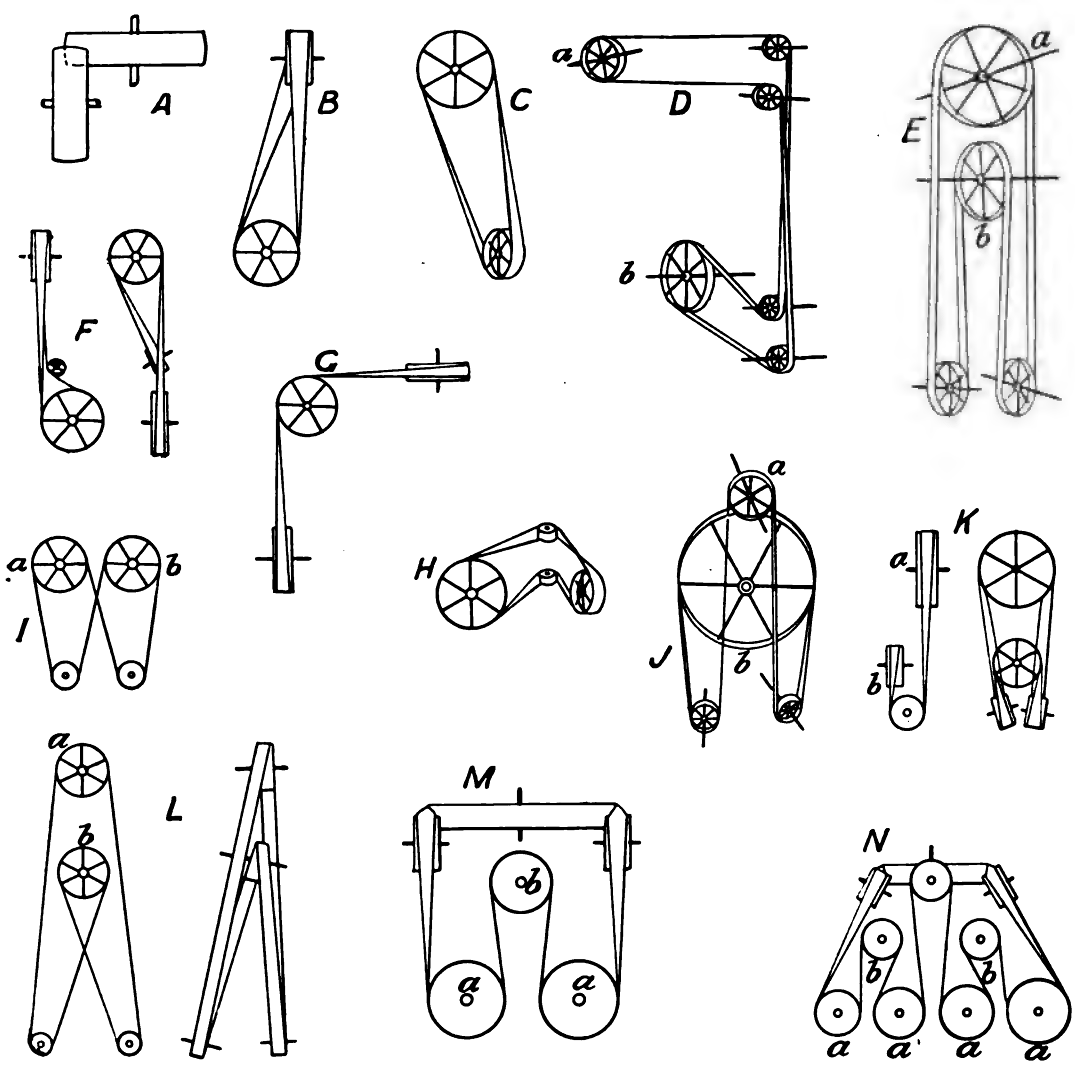


Fig. 122.

REFERENCES.

A. Edges of driving and driven pulleys in same plane. *B*. Belt drive between pulleys at right angles. *C*. Quarter-twist drive. *D*. Shafts *a*, *b* at right angles, driven by belting carried over guide pulleys, so equalising strain in the belt. *E*. Pulleys *a*, *b* at right angles, and very close together, driven through guide pulleys. *F*. Quarter-twist drive, in which the twist of the belt is removed by a guide pulley. *G*. Shafts connected at right angles, but requiring a guide pulley. *H*. Belt driving two parallel shafts, not in the same plane, using guide pulleys. *I*. Pulleys *a*, *b* very close together, driven with crossed belt brought round guide pulleys. *J*. Pulleys *a*, *b* too near for direct driving, driven indirectly through guide pulleys. *K*. Belt driving parallel shafts *a*, *b* not in the same plane. *L*. Pulleys *a*, *b* driven indirectly over guide pulleys. *M*. Two spindles *a*, *a* driven by one belt over guide pulleys; *b*, tightening pulley. *N*. Four spindles driven similarly.

$\frac{7}{32}$nds, or 0·219 inch thickness was found to be 200 lb. per inch of width, when the rupture occurred through the laced joints. When through the rivet holes of the splices, the strength was more than half as much again. Through the solid leather, the strength was 675 lb. per inch of width.

Leloutre in 1878 made a large number of experiments on belts. One series consisted in cutting thongs from different belts, and loading them with weights. The maximum resistance to stretching of ordinary leather was found to exist at a load of 850 lb. per square inch. He determined the slip in the same way as Morin and Towne, by hanging weights on belts suspended over stationary pulleys, and with arcs of contact varying from 180 to 260. The coefficient found for new leather belts was 0·155, for old greasy ones 0·20 to 0·22.

Mr Wilfred Lewis conducted experiments in 1886 for Messrs W. Sellers & Co., to determine the slip, and efficiency of belting. He gathered that with belting properly arranged, the slip should not exceed from $1\frac{1}{2}$ to 2 per cent. The total efficiency was estimated to be 97 per cent. of the gross load, which by the way accorded with an experiment of M. Leloutre giving 95 to 96 per cent. efficiency.

In 1882 Professor Holman experimented with varying speeds of slip, with the object of ascertaining why so great discrepancies occurred in the coefficients, as in 0·58, down to 0·12, obtained by Morin and Towne.

Professor Laiza in 1886 ascertained by experiments that the average speed of slip of a belt under ordinary working conditions is from 3 to 12 feet per minute, and at that speed the coefficient of friction has a mean value of 0·27.

The result of these experiments is that the limit of load for ordinary working conditions beyond which a belt will slip on its pulley is closely determined as 0·27. If kept within that limit, no excessive loss need occur.

Actually in shop practice, a slip of 3 to 12 feet a minute is often much exceeded. But this only shows the difficulty of applying formulæ to cases in practice. Elasticity of belts, or their stiffness, the effect of high speeds, giving rise to centrifugal action, and so lessening the coefficient, the effect of air between the belt and pulley all introduce conditions which do not exist in carefully arranged experiments.

A single belt measures from $\frac{3}{16}$ths to $\frac{5}{16}$ths inch in thickness; a double one from $\frac{3}{8}$th to $\frac{3}{4}$ inch. The ultimate strength of a leather belt is from 3000 to 8000 lb. per square inch of section. But at the laced joint, which measures the real or working strength, it is only about 320 lb. per square inch of section. A double belt will transmit about twice the power of a single one, and therefore for the same power requires to be only half the width of the former. 80 lb. working tension may be taken for a single belt, and 140 for double, which will be the maximum tension allowable on the tight or driving side. The horse power of a belt depends on its strength and speed and on the arc of contact which it makes with its pulleys. If the difference in the diameter of these is great, the frictional grip on the smaller pulley will be the controlling condition, especially when the centres are rather near to each other. In using the tables given by manufacturers allowance must be made for this by increasing the belt width. The tension on the tight side being taken at 80 lb. in single belts and 140 in double, the coefficient of friction being taken as 0·4, and the arc of contact 150°, the available proportion of the working tension is 65 per cent., or $80 - 28 = 52$ lb. for single, and $140 - 46 = 94$ lb. for double belts respectively, per inch of width.

The table on next page, abridged from one by the Unbreakable Pulley & Mill Gearing Co., Ltd., has been calculated from these data, and on an arc of 150° of the smaller pulley. The percentages of working tension with different arcs of contact are as follows:—

For arcs in degrees	110	120	130	140	150	160	170	180
Proportion is	·54	·57	·60	·62	·65	·67	·69	·71

Very high speeds are not economical in belt drives, due to the action of centrifugal force, which increases as the square of the speed, while the power transmitted increases only directly. It will be noted that efficiency increases until 4,000 feet a minute is passed, after which it diminishes.

To find the velocity of a belt in feet per

Table of Horse Powers that good quality Single Leather Belts of different widths will transmit at various speeds.

The Unbreakable Pulley & Mill Gearing Company, Ltd.

Table of Horse Powers that good, medium thickness Double Leather Belting will transmit at various speeds.

Velocity in Feet per Minute.	Width of Belt, in Inches.										Width of Belt, in Inches.							
	2	3	4	5	6	7	8	9	10	20	1	2	3	4	6	8	10	20
100	·31	·47	·63	·79	·94	1·1	1·3	1·4	1·6	3·1	·28	·57	·85	1·1	1·7	2·3	2·8	5·7
200	·63	·94	1·3	1·6	1·9	2·2	2·5	2·8	3·1	6·3	·57	1·1	1·7	2·3	3·4	4·6	5·7	11·4
300	·94	1·4	1·9	2·4	2·8	3·3	3·8	4·2	4·7	9·4	·85	1·7	2·6	3·4	5·1	6·8	8·5	17·1
400	1·2	1·9	2·5	3·1	3·8	4·4	5·0	5·6	6·3	12·5	1·1	2·3	3·4	4·5	6·8	9·1	11·4	22·7
500	1·6	2·3	3·1	3·9	4·7	5·5	6·3	7·1	7·8	15·7	1·4	2·8	4·3	5·7	8·5	11·3	14·2	28·4
600	1·9	2·8	3·8	4·7	5·6	6·6	7·5	8·4	9·4	18·8	1·7	3·4	5·1	6·8	10·2	13·6	17·0	34·0
700	2·2	3·3	4·4	5·5	6·5	7·6	8·7	9·8	10·9	21·8	2·0	4·0	5·9	7·9	11·9	15·8	19·8	39·5
800	2·5	3·7	5·0	6·2	7·5	8·7	10·0	11·2	12·4	24·9	2·3	4·5	6·8	9·0	13·5	18·0	22·5	45·1
900	2·8	4·2	5·6	7·0	8·4	9·7	11·2	12·6	14·0	27·9	2·5	5·1	7·6	10·1	15·2	20·2	25·3	50·5
1000	3·1	4·6	6·2	7·7	9·3	10·8	12·4	13·9	15·4	30·9	2·8	5·6	8·4	11·2	16·8	22·4	28·0	55·9
1200	3·7	5·5	7·4	9·2	11·0	12·9	14·7	16·6	18·4	36·8	3·3	6·7	10·0	13·3	20·0	26·6	33·3	66·5
1400	4·2	6·4	8·5	10·6	12·8	14·9	17·0	19·1	21·3	42·5	3·8	7·7	11·5	15·4	23·0	30·7	38·4	76·8
1600	4·8	7·2	9·6	12·0	14·4	16·8	19·2	21·6	24·1	48·1	4·3	8·7	13·0	17·3	26·0	34·7	43·4	86·7
1800	5·3	8·0	10·7	13·4	16·0	18·7	21·4	24·0	26·7	53·4	4·8	9·6	14·4	19·2	28·9	38·5	48·1	96·2
2000	5·8	8·8	11·7	14·6	17·6	20·5	23·4	26·3	29·2	59·0	5·3	10·5	15·8	21·0	31·6	42·1	52·6	105·0
2200	6·3	9·5	12·7	15·8	19·0	22·2	25·3	28·5	31·7	63·3	5·7	11·4	17·0	22·7	34·1	45·5	56·8	114·0
2600	7·2	10·8	14·4	18·0	21·6	25·2	28·8	32·4	36·0	72·1	6·4	12·9	19·3	25·8	38·6	51·5	64·4	129·0
3000	7·9	11·9	15·9	19·9	23·8	27·8	31·8	35·8	39·7	79·5	7·1	14·1	21·2	28·2	42·3	56·5	70·6	141·0
3400	8·5	12·8	17·0	21·3	25·6	29·8	34·1	38·4	42·6	85·2	7·5	15·0	22·6	30·1	45·1	60·1	75·2	150·0
3800	8·9	13·4	17·8	22·3	26·8	31·2	35·7	40·1	44·6	89·2	7·8	15·6	23·4	31·2	46·8	62·4	78·0	156·0
4000	9·0	13·6	18·1	22·6	27·1	31·6	36·2	40·7	45·2	90·4	7·9	15·7	23·6	31·4	47·2	62·9	78·6	157·0
4400	9·1	13·7	18·3	22·8	27·4	32·0	36·5	41·1	45·7	91·3	7·8	15·6	23·5	31·3	46·9	62·6	78·2	156·0
4800	9·0	13·5	18·0	22·4	26·9	31·4	35·9	40·4	44·9	89·8	7·6	15·1	22·7	30·2	45·3	60·4	75·5	151·0
5000	8·8	13·2	17·6	22·0	26·4	30·8	35·2	39·6	44·0	88·1	7·3	14·7	22·0	29·3	44·0	58·6	73·3	147·0
6000	6·9	10·4	13·8	17·3	20·7	24·2	27·6	31·1	34·6	69·1	5·1	10·3	15·4	20·5	30·8	41·1	51·3	103·0

minute, the pulley diameter, and number of revolutions per minute being given.

Rule.—Find the circumference of the pulley in feet. Multiplying this by the number of revolutions per minute gives the belt speed in feet per minute.

Approximate Weight of Leather Belting in Lb. per 100 Feet in Length.

Width in Inches - -	3	4	5	6	7	8	9	10	12
Single Belts—Strong -	31	43	55	67	79	94	109	125	160
„ Medium	29	41	52	64	75	89	103	118	150
Double Belts—Strong -	59	83	100	120	145	172	200	230	280
„ Medium	53	76	92	110	135	160	186	215	265

Belt Polishing Machine or **Belt Strapping Machine.**—A type of machine used for polishing with emery, &c., in which the work is presented to a belt charged with abrasive powder, and traversed at a high speed over pulleys. The machines are made in two leading types, horizontal, and vertical, Fig. 123, corresponding with the relative positions of the pulleys. Support in the former is afforded against the pressure of the work by a rest on the underside of the belt, and in the latter by tension pulleys. In each, one of the main driving pulleys has a tension arrangement, by which the necessary tension can be put on the belt to avoid slip, and by which belts can be taken off, and changed quickly. The belts used range from about $\frac{3}{4}$ in.

to 3 in. in width. They are made of two thicknesses of duck, with a layer of vulcanised rubber between, and they are charged with emery of various degrees of fineness. The pulleys make from 400 to 500 revolutions per minute.

The advantage which these machines possess over solid wheels is in the case of articles that are curved and which can only be reached by a flexible agent. They are therefore used by brass-finishers, cycle makers, and electroplaters.

Belt Pulleys.—The pulleys which are used for transmission of power by flat belts, and are thus distinguished from those adapted for ropes and chains; and also from drums, which are much elongated pulleys for traversing belts.

The essentials of a good pulley are lightness, strength to resist stresses due to centrifugal force, freedom from internal strains, perfect balance, retention of its belt at all speeds, suitable facilities for ready hanging in place, and moderate cost, because of the large numbers required in a factory.

Lightness in large pulleys is inconsistent with the use of cast iron, and this is one of the reasons why those with rim and arms built up of steel, and those of wood have come into extensive use. Cast-iron pulleys cannot be made both strong and light, and in the endeavour to secure strength internal stresses are frequently set up which are a source of danger. Neither is it easy to obtain perfect balance in cast-iron pulleys.

The chief difficulties in the manufacture of cast-iron pulleys are the maintenance of due proportions between rim, arms, and boss, Fig. 124. The thin metal quickly cooling should all cool down simultaneously, for if any portion continues shrinking after other portions, it will strain the part that has set, and will, if the contraction is prolonged, cause fracture, either at the time, or subsequently. For this reason, set rules and formulæ for the proportions of pulley parts have little value, since slight differences invalidate them. The only safe guide is experience of such work, by the aid of which a man is able at a glance to say whether a pulley is safe or no. For instance, it does not answer, if a pulley is found to be properly pro-

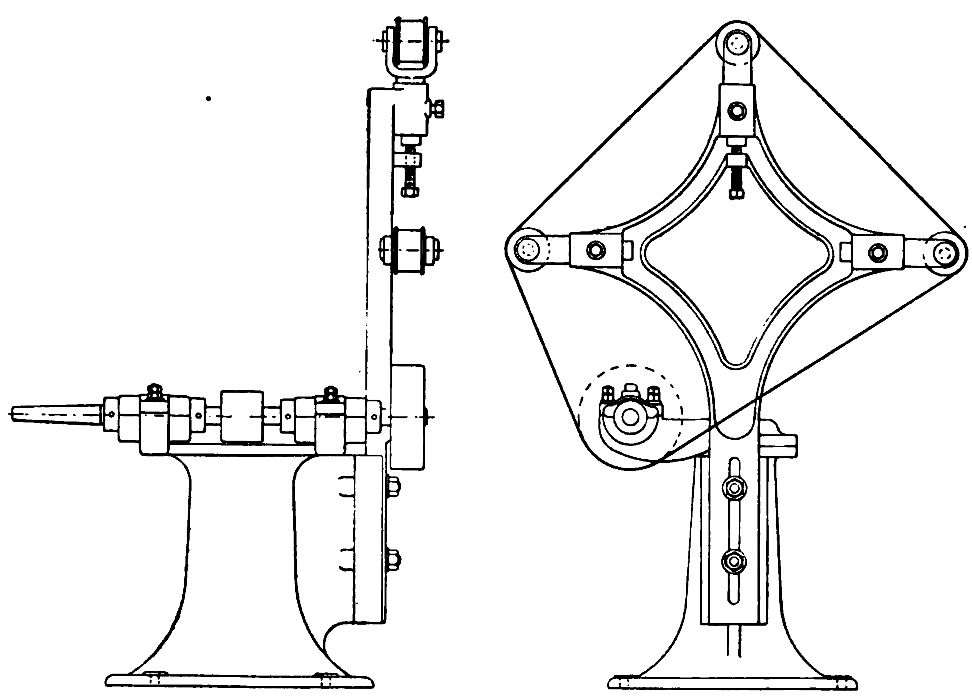


Fig. 123.—Belt Polishing Machine.

portioned, to make either rim or arms alone a little heavier or lighter; rims being often thickened in order to give more metal for extra crowning, or arms thickened or ribbed to impart additional strength there. If one part is strengthened, the other parts must also be. The three elements, rim, arms, and boss, are each mutually tied together, and a very slight disturbance of their tensile equilibrium either permanently strains, or produces actual fracture.

More fractures are caused by having a boss too large than by any others. Naturally the boss takes longest to cool, and in doing so, shrinks inwards, and puts the arms into tension, and this again sets up tension in the rim. It is therefore necessary to keep down the boss thickness to a minimum, and when keyway grooves are wanted these should have key bosses, instead of thickening the main boss all round alike.

If a large boss is unavoidable, as in the case of a shaft of large diameter, or if a boss is very long, two courses are open, either to uncover and cool the boss, or to recess the central portions with a chambered core. It is surprising how effective even a slight amount of chambering is in relieving a big boss of strains and draws.

The question of the shapes of arms comes in here. In English practice these are curved, excepting in the smallest sizes, curves being single in those of medium diameters, double in the larger. It is believed that this curving affords a degree of elasticity to the arms, by virtue of which they are able to accommodate themselves to cooling stresses and strains. In America most pulleys have straight arms, the elasticity theory being discredited. It is probable that the value of curving has been overrated, for cast iron possesses but slight elasticity. Many pulleys with arms well curved do break, so we conclude that safety lies much more in proper proportions than in the shape of the arms.

The crowning of pulleys is done to lessen risk of the belt running off. This is often overdone. At high speeds the centrifugal force causes the outer portions of a wide belt to lift away from contact with the rim. In losing contact, some driving power is sacrificed, and slip occurs. In practice, crowning ranges from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch per foot of width, but the former need not be exceeded when the pulleys are in perfect alignment. Flanges are sometimes added to confine the belts, but unless absolutely necessary they are better done without, as they chafe and wear the edges of belts, particularly the woven ones.

The troubles incidental to cast-iron pulleys have been the cause of the development of the built-up pulleys, first of wrought iron, and then of steel. These are lighter, free from the evils incidental to shrinkage strains, and well balanced, and they can be had with or without crowning, and with or without flanges. Various methods of manufacture are adopted by different firms. Objections to these pulleys are that they are often wanting in rigidity, and in truth in the rim, and that the casting-in of the arms to the boss injures the metal.

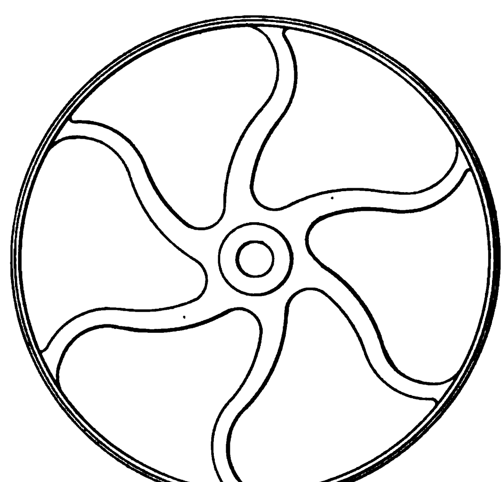


Fig. 124.—Cast-iron Pulley.

Small pulleys both of the cast, and of the sheet metal types, are made with solid plated centres. Larger sizes are also made thus for high speed drives to lessen the air resistance. Dynamo pulleys for example generally have plated webs for this reason.

The wood pulleys are very popular. They are built up in segments in pattern fashion, and the centres are either plated, or arms are fitted. These pulleys have the merit of light-

ness. They also stand the heat of the shops pretty well, and are suitable alike for the smallest and the largest sizes.

There are many pulleys on the market in which no casting is adopted, but the boss, like arms and rim, is produced from sheet metal, cold pressed. The rim is stiffened by turning round into a beading on each inner edge, which does away at once with the objectionable thin weak rim. The arms are strutted also (*see* Figs. 125, 126). The battle between the cast and sheet metal pulleys still goes on, so that it is possible are very light, the rim is stiff by virtue of the internal flanges on each edge, or by the beading. Some are made in two thicknesses of steel, others in one only. The arms are attached to an internal central flange produced by turning the rim sheets inwards there and riveting, and the rim lugs are riveted to these. The arms or spiders are both strutted, and corrugated in cross-section, to afford stiffness. The boss is of pressed steel, comprising bushings, and clamps. The boss ends of the arms are spread out, or flanged in one type, to be

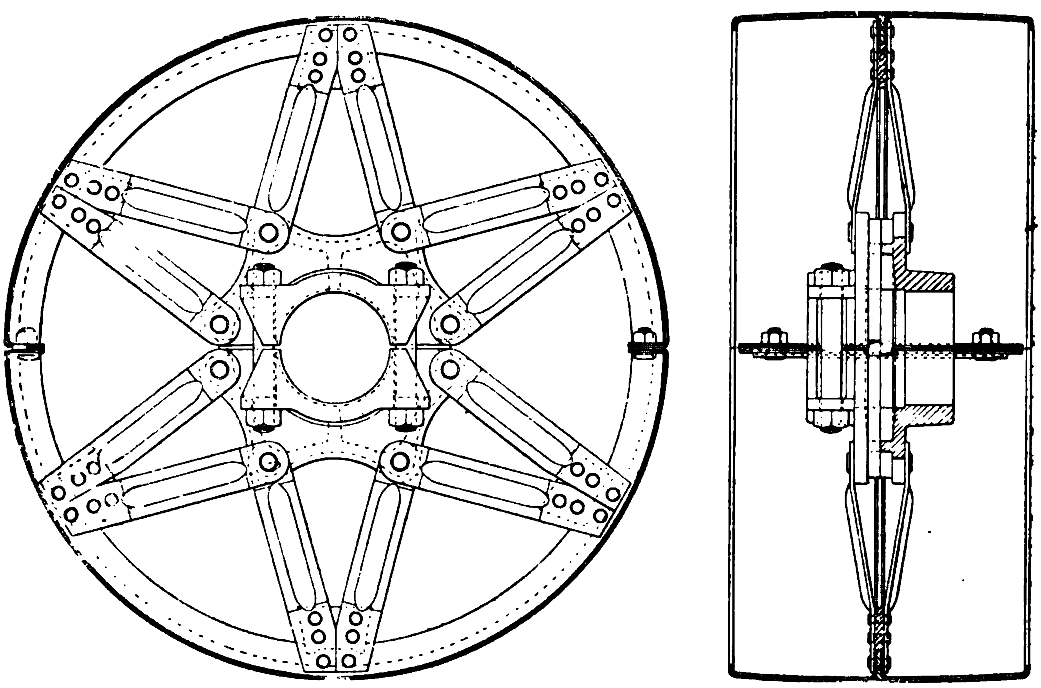


Fig. 125.—24-Inch Philips' Pressed Steel Pulley with Reinforced Central Rib.

now to get very good articles of either class. As wood pulleys have proved serious rivals to the heavy ones of cast iron, and those built up of steel, they are now in turn being attacked by this very light type, made exclusively of pressed steel, in which the objections to the cast boss, and the unstiffened rim are non-existent.

In accordance with present day ideas these pulleys are made in halves for convenience of gripping a shaft in any location, and they hold without keys by the simple tightening up of the bolts which unite the halves. Though they embraced between the bushings, and the clamps; in another the arms are riveted to lugs on the central bushings.

The methods of fitting pulleys to their shafts are generally by bored holes embracing the shafts closely by pushing or driving on, and keying. The objection to this is that it is not an elastic system, for unless the fitting is perfect, extra work is involved, and with unsatisfactory results. To obviate this is the reason for the employment of loose bushes, and the screwing of the pulley boss to suit the exterior of a large range of bush bores, Fig. 127.

The standard pulleys for a good range of bores are screwed to a few sizes only, and the bushes are bored to suit any shafts within this range. The bushes are hinged, A, being opened out to embrace the shaft at B; they are closed by the screwing over them of the pulley boss. There is the great advantage besides that the fitting of keys is avoided.

Wood pulleys are bushed with interchangeable bushes, the standard pulley being made with a standard hole to which bushings of any size can be fitted.

The other method of fitting is by splitting pulleys, and putting them over their shafts in halves. This is actually necessary only when they cannot be slid on endwise, in consequence of something else, as other pulleys or bearings occupying the ends of a shaft already in place.

In nearly all additions made to shafting split pulleys must be employed.

Splitting is done through boss and rim by means of lugs, through which the bolts pass, Fig. 128. In the smaller pulleys the practice generally is to cast plates right across from boss to rim and put the bolts through these, Fig. 129.

Fast and loose pulleys differ in respect of the boss, sometimes also of the rim. Thus the rim of the loose pulley is often $\frac{1}{4}$ in. or $\frac{1}{2}$ in. smaller in diameter than that of the fast pulley, so that the belt when not driving shall run slackly, and not stretch unnecessarily.

The bosses of loose pulleys are often made smaller than those of their fast companions, because they are not keyed, and they sustain less stress as they do not drive. But for convenience

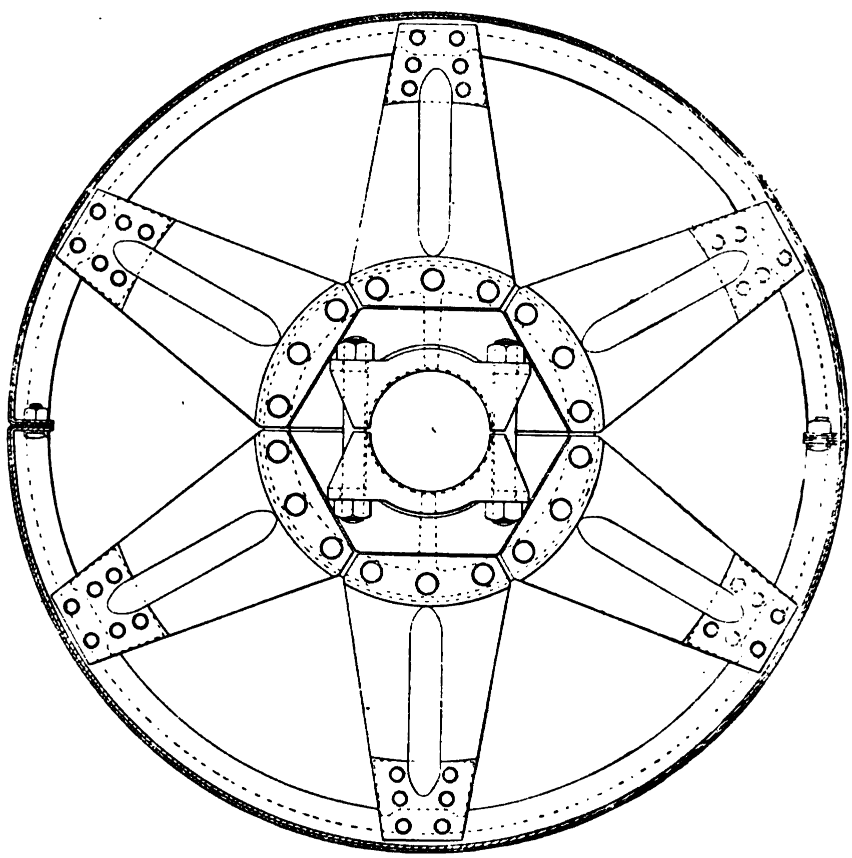


Fig. 126.—24-Inch Philips' Pressed Steel Pulley for extra heavy duty.

they are frequently made of the same diameter, and if they are bushed they are also of the same size.

Bushing with brass is frequently practiced,

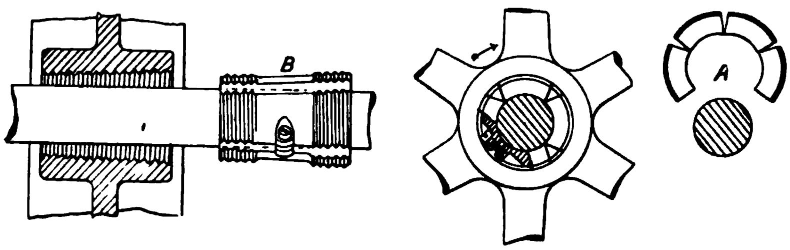


Fig. 127.—Screw Bush. (Smith & Grace Screw Boss Pulley Co., Ltd.)

because it lessens the wear on the shaft, and the bush can be more easily renewed than a new pulley. The bushes are in ordinary practice driven in tightly. But there are improved forms which are self-oiling; some are designed to serve both as bush and collar.

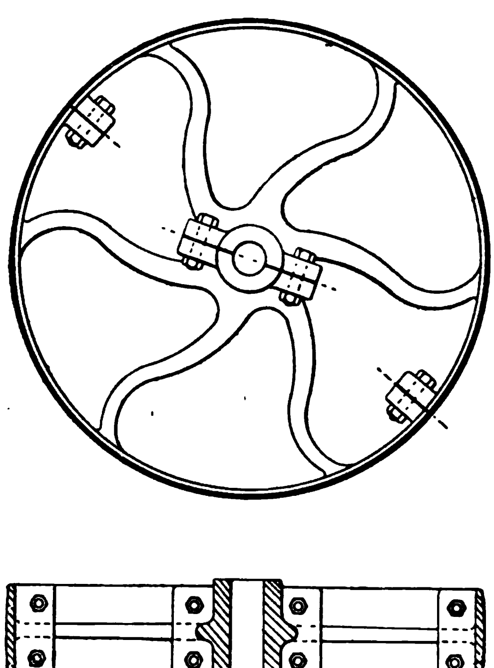


Fig. 128.—Split Cast-iron Pulley.

The casting of pulleys is done differently according to whether the work is occasional or repetitive. The latter is often done by machine, —*see* **Pulley Moulding Machines**. But the following brief account describes the method suitable for a good run of business.

Plain rim patterns of iron (without arms) are prepared in as many stock sizes as the pulleys are to be made. They are turned all over of parallel thickness (no crowning being put on the pattern). Two such sets for each diameter may be made, one being extra thick for curving. Or an ordinary thinner pattern sometimes has its thickness increased in the mould by laying wood strips around it, sleeking the mould by their guidance. The pulley rims are uniformly from 12 to 16 inches deep. Moulds deeper than this are made by "drawing" the pattern, shallower ones by stopping down.

The pulley arms are made separately of cast iron, and without bosses, a hole being bored in the centre to receive bosses of different sizes. Two sets of arms are made for each size of pulley, one light, of elliptical section; the other heavier, with ribbing to suit light and heavy pulleys respectively, or those without and with crowning. These simply fit loosely within the rims, and are set to their proper depths by the moulder with the aid of a templet.

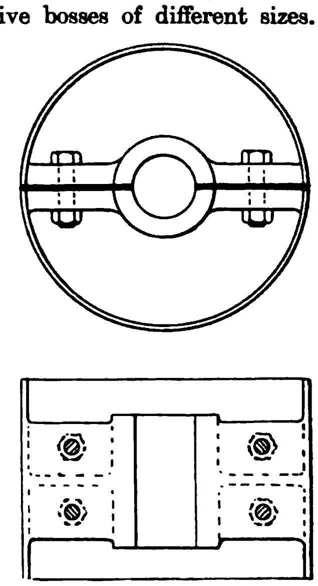


Fig. 129.—Split Small Cast-iron Pulley.

All the conditions are here present for making pulleys of a given diameter to any depth, and with any diameter and depth of boss, and all accurately and without makeshift. When double arms have to be cast they are laid in the mould at their proper distances apart,

and the space between the joints, corresponding with the middle planes of the arms, is made as a sand core, lifted on grids. For the smallest pulleys a plain disc is substituted for arms, also with a centre hole to receive bosses of different sizes.

The methods of splitting pulleys are as follows:—

Pattern lugs are fitted, each with a print for the splitting plate. No provision is made for the bolt holes by prints on the lugs, but holes are made in the splitting plates to carry the cores for the bolt holes. The plates are loamed over, dried, and oiled or tarred before insertion in place. They are cast in, to be knocked out after casting, and used again, or new plates substituted in the pulley lugs. The pulley is split right through, excepting just the rim thickness.

To find the number of revolutions of a driven pulley; having the number of revolutions of the driving pulley, and the diameters of both pulleys being given.

Rule.—Multiply the diameter of the driving pulley by its number of revolutions per minute, and divide the product by the diameter of the driven pulley.

To find the diameter of a driven pulley to make a given number of revolutions per minute; the diameter and number of revolutions per minute of the driving pulley being given.

Rule.—Multiply the number of revolutions of the driving pulley by the diameter of that pulley, and divide the result by the required number of revolutions of the driven pulley.

To find the diameter of a driving pulley; the diameter of the driven pulley, and the number of revolutions of each being given.

Rule.—Multiply the diameter of the driven pulley by the number of revolutions at which it is required to run, and divide the product by the number of revolutions of the driving pulley.

Belt Pump.—Any pump that is driven by belting.

Belt Punch.—*See* **Belting.**

Belt Rivets.—*See* **Belting.**

Belt Screws.—*See* **Belting.**

Belt Shipper.—*See* **Striking Gear.**

Belt Tension.—When a belt is used as a means of transmission between pulleys, one side, the driving, is tight, the other is idle or slack. The difference in the two tensions is the tension available for working. The tension on the slack side is due to the arc of contact of the pulley, the coefficient of friction, and the effect of centrifugal force.

Bench.—*Benches for wood-work*, Figs. 130, 131, are provided with a stop as a resistance for planing against, and a vice, generally of wood, both near the left-hand end, and at the front edge. The bench is usually made entirely of wood, though occasionally metal standards are employed instead of wooden legs. Hard or soft woods are employed, or a combination of both. Beech is the best for the purpose, as it is hard, straight, even in texture, and not liable to warp. Ash is the only other hard wood that is commonly used for benches. When made of soft wood, yellow pine, or cheap deal is used. Yellow pine is good in every way except that it is too soft for parts subjected to wear. Deal is oftener used because it resists wear better and is cheaper. Whatever wood is adopted, the top of the bench, along the front part where the wear is heaviest, requires renewal occasionally unless the bench is used only for a very rough class of work. The plank here should

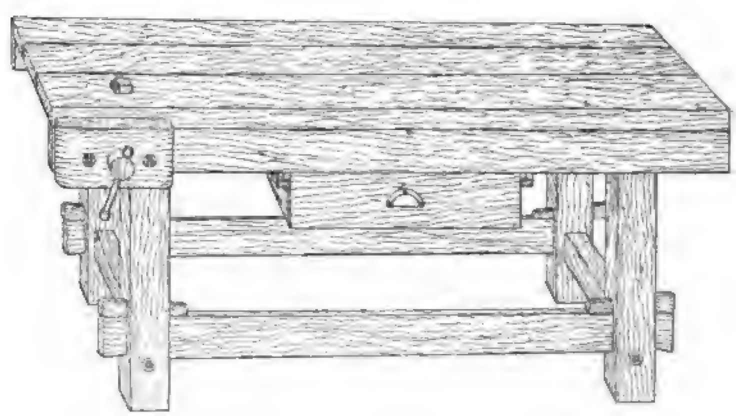


Fig. 130.—Wood-worker's Bench.

not be less than 2 inches thick—and on a large bench should be 3 inches. The planks beyond, where there is comparatively little wear, and accuracy is of less importance, are sometimes thinner. They may then either be blocked up to the level of the thick part, or allowed to remain below. The latter method is convenient because it permits tools and chips to be cleared on to the lower level and large work more conveniently moved about on the higher surface. Another good method of obtaining this result is to put an additional plank on top of the original surface. This can then easily be renewed afterwards merely by changing the top plank.

A wood-worker's bench should be rigid and

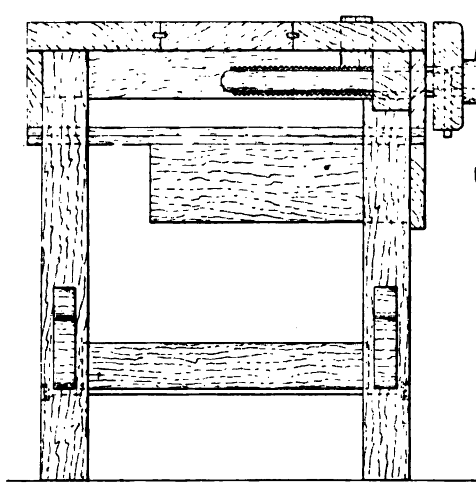


Fig. 131.—End View of Wood-worker's Bench.

heavy to withstand the strain of heavy planing. For convenience, there are other fixtures which, though not essential, are sometimes attached to benches. One of these is a means of holding the wood down, and pressing it forward against the stop to prevent it from slipping during planing. A method very popular in Germany is a second vice at the back end of the bench, and a series of holes along the bench so that the stop can be inserted to suit different lengths of wood. A stop in the back vice then enables the wood to be squeezed endwise between the two stops. The back vice is also useful for other purposes. Another device is a bench knife adjustable at any position along the bench. This also presses the wood from behind. Another convenience for planing edges of long pieces of wood which are held in the vice at their front end, is an adjustable peg at the side of the bench for the back end of the wood to rest on. The stop which is used for planing against must be adjustable vertically so that it can be lowered for very thin wood, and raised high enough to prevent thicker pieces from jumping over it during planing. Stops are made in various forms both in wood and metal. A drawer for tools is convenient, and a platform below, and also a shelf in each end, are useful for storing things that are frequently required on the bench.

Benches are made in all sizes. They may be constructed to go against a wall, or to stand out in the open, and have a vice and stop on each side, so that two men can work on them. Or they may be made very long and have a number of vices, a method common in pattern shops for long patterns. Even single benches vary greatly in size, especially in length, according to the work they are required for. In height the limits for all benches are generally between 2 ft. 6 in. and 3 ft. Single benches are seldom more than 2 ft. in width. Double ones not less than 3 ft.

The metal-worker's bench is often constructed in timber very much like that of the wood-worker, but a cast-iron frame is better suited to the service required, because it is more rigid and neat, and does not absorb oil and dirt, which are unavoidable in much fitters' work, a consideration scarcely arising in the more cleanly wood-working trades. A good example of such a bench is shown in Fig. 132, comprising two ribbed frames, bolted together, with a piece of planking interposed, which stands up to form a partition between the halves of the bench, and carries a small ledge or shelf. 2-inch planks are screwed on the top of the frame, and a hard-wood (preferably maple) facing attached to these, the facing being tongued together as seen in the front view, showing the drawer fitting.

Two other shelves are placed on the bottom ledges to carry pieces of work, &c. The upright planks keep the work from falling back. The vices are bolted down through the deep bosses seen near the front edges of the bench. If a wall

is available, one half frame may be dispensed with, and a single section placed up against the wall. The legs are located at about 5-feet spacing along the bench run, to give adequate rigidity and support to the planking. The height from the floor to the bench top is about 2 ft. 10 in., and the width about 2 ft. 6 in., which makes the double bench shown 5 feet across. Coach screws are employed to bolt the feet to the floor, through the lugs seen.

Bench Drilling Machine.—This cannot be said to denote any special type of drill, but

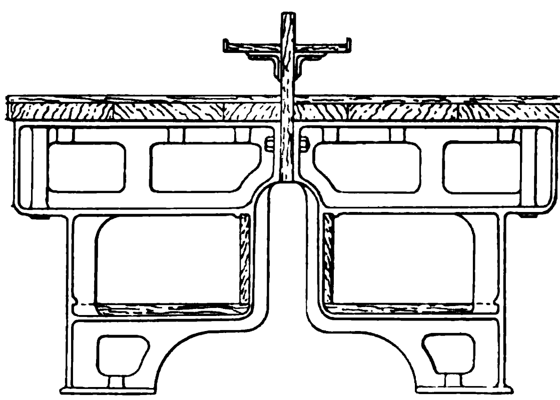


Fig. 132.—Bench for Fitters and Metal-workers.

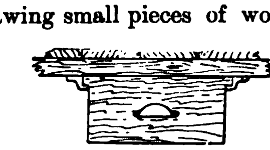
refers to the method of carrying it on a bench instead of upon a separate stand. The method is frequently followed in jobbing shops where the small drill is in constant request by workers at the vice, and in manufacturing establishments where a long bench forms the most convenient method of mounting a number of light drills, which may or may not be used in conjunction with other tools.

Bench drills are hand or power driven, and may be of the ordinary screw feeding, or of the sensitive type. Their capacity does not usually exceed ½-inch or ¾-inch holes. References to the various types of drills will be found under suitable heads.

Bench Grinder.— Small grinders using emery and other wheels are frequently fastened upon a bench for the same reasons that drills are—to save the expense of a separate stand, and for greater convenience to vice workers. Tool sharpeners form a considerable proportion of the small grinders thus mounted, being located about in handy positions. For those using water on the wheel, a tray must be provided beneath to keep the water from soaking into the wood. Small cutter, and twist-drill grinders are also mounted similarly on the bench, as well as polishing wheels.

The smallest machines have but one wheel, sometimes not exceeding 6 inches diameter, but it is generally advantageous to provide a double-ended spindle, carrying two wheels of varying shape and grades. Rests may or may not be employed, depending on the class of work done.

Bench Hook.—A block of wood used by wood-workers for taking the thrust of a saw in sawing small pieces of wood on the bench, Fig. 133. It measures about 8 inches long, by 3 inches, by 1 inch, and has a projecting portion on the opposite face of each end. When laid in position, the under projection presses against the edge of the bench, and the upper projection at the far end serves as a stop against which the piece of wood to be sawn is held with the left hand while the saw is used with the right.



Bench Knife.—A bit of an old knife, used by pattern-makers for retaining the rear end of a strip of wood from lateral movement on the bench while being planed. It is driven partly into the end of the strip, partly into the bench.

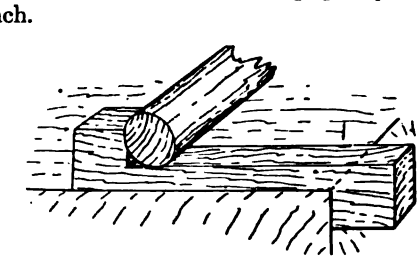


Fig. 133.—Bench Hook.

Bench Lathe.—Any small lathe which is mounted on a bench instead of on separate legs may be classed thus, but the term has come to mean specially a high class type, for doing the finest kinds of work, and possessing several features not found in other lathes. The dimensions are limited, generally not exceeding about 4 to 5-inch centres, and length of

bed 3 feet, and a number of special attachments are employed. Details of a Pratt & Whitney lathe, swinging 7-inch diameter over the bed, and taking 18 inches between centres, are shown in the accompanying drawings. The bed, Fig. 134, is cast solid with its feet, and is a portion of a circle in cross-section, giving

A double ring of index holes is drilled in the cone pulley rim, and an index pin, seen, springs into either of these. The clamping of the headstock upon the bed is through the medium of the plunger bolt seen in section, which is drawn upwards by the eccentric spindle, turned by the little handle. A spiral

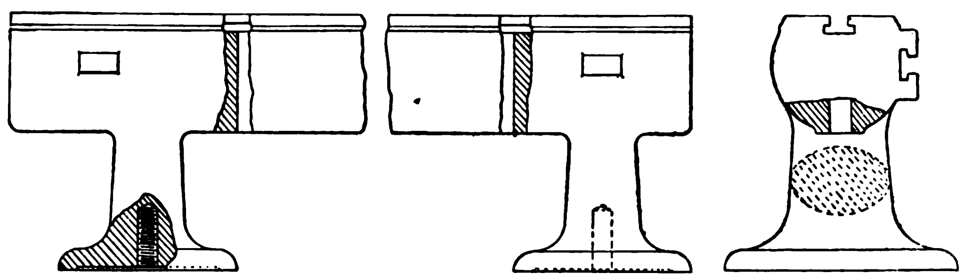


Fig. 134.—Bed of Bench Lathe.

a very rigid construction. A tee slot runs along the top, and one at the back, while a clear slot cuts through the bed, as seen, for a clamping bolt to hold various attachments. The headstock, Fig. 135, has a three-stepped pulley, driving a hollow spindle, which is fitted with a draw-in tube, to hold various chucks and fittings. Fig. 136 shows details of the gripping of two forms of split chucks, that to

spring above loosens the plunger bolt as the eccentric is turned downwards.

Several styles of poppets are employed on the lathe; one is of standard form with screw and handwheel operating the barrel, which we need not illustrate, but the others are special. The lever style, Fig. 137, is chiefly employed for drilling and recessing, the spindle barrel being moved to and fro by a pinion and handle, the former meshing with a rack cut upon the underside of the barrel. A stop screw at the rear provides for definite depthing. The locking to the bed is effected in a similar manner to that of the fixed headstock. The half-open tailstock, Fig. 138, is another peculiar fitting, being

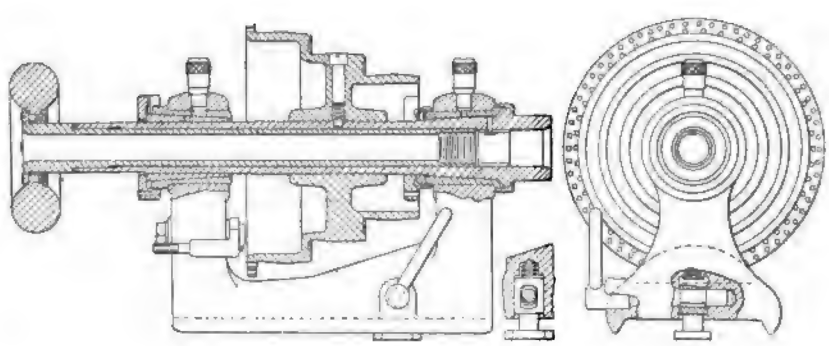


Fig. 135.—Headstock of Bench Lathe.

the left being a type for holding wire, the pulling backwards of the coned diameter at the front contracting the hole upon the work. That to the right is a step chuck, closed in the same manner, but having a large disc provided with a number of steps or shoulders, which grip work suited to them, chiefly shallow pieces to be faced or otherwise operated on.

open at the top, so that the spindle may be lifted out, which is done in order that several different spindles may be substituted in rapid succession. One may, for instance, carry a drill, another a countersink, another a tap. The yoke attached to each spindle at the rear embraces the guiding bar inserted in the poppet back, and keeps the spindle from

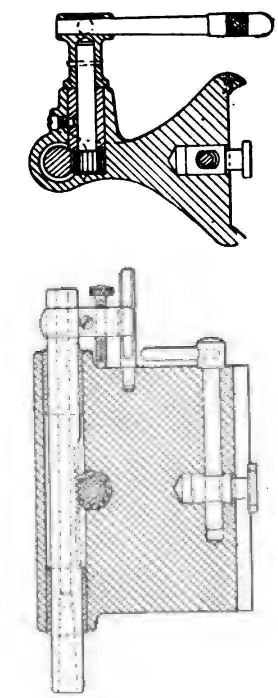


Fig. 137.—Lever Type of Tailstock for Bench Lathe.

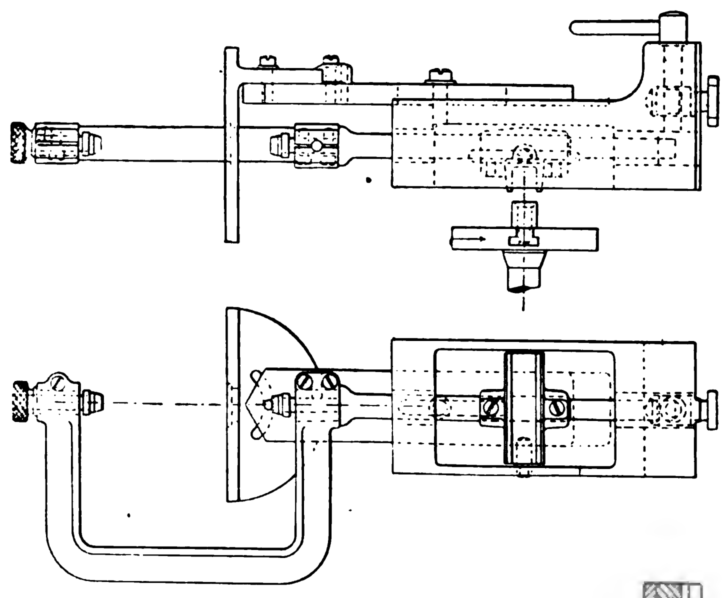


Fig. 140.—Filing Attachment for Bench Lathe.

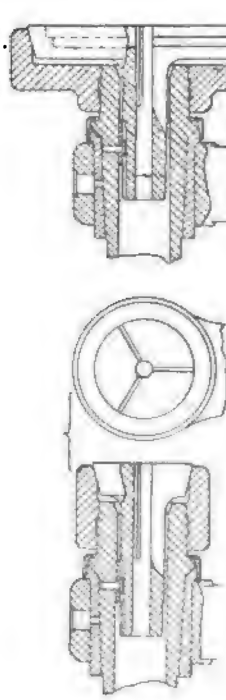


Fig. 136.—Split Chucks for Bench Lathe.

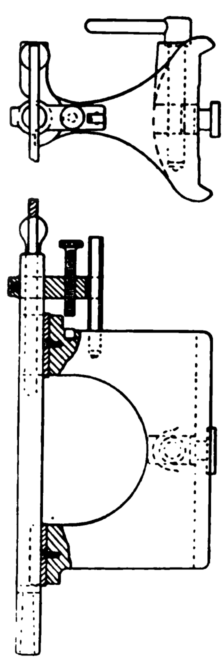


Fig. 138.—Open Type of Tailstock for Bench Lathe.

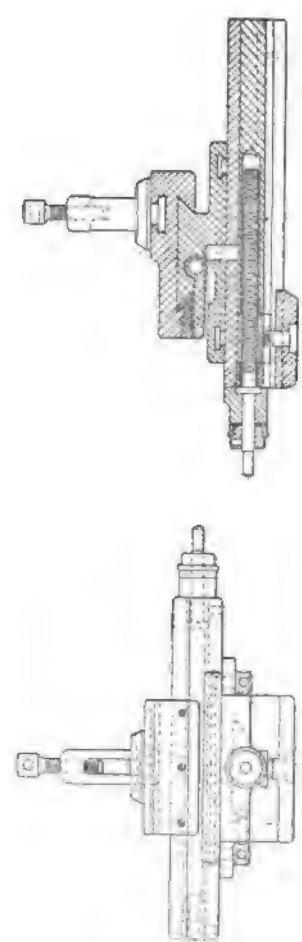


Fig. 139.—Slide Rest of Bench Lathe.

rotating. The spindle is moved to and fro by a pivoted lever shown.

Another style of tailstock (not shown) is similar to Fig. 137, but has a cross working slide, in order that facing and similar operations may be effected.

The slide rest, Fig. 139, has concealed screws, as seen, and a swivel base; ball handles are used on the screw ends, though not shown. The tool post is of single screw pattern. A special double type of rest is also employed, having front and rear slides, so that turning, forming, cutting off, &c., can be done without having to change tools. A rest is also fitted revolves. The swivelling table has a graduated arc, to set to definite angles, and small files, saws, or diamond laps held in the chucks pass through a bush in the table, and rectify hardened work, or perform delicate sawing, &c.

A milling attachment, Fig. 141, bolted to the bed, carries a spindle with division plates, and slides to move this up, and down, and crosswise in both directions. The hollow spindle takes the same fittings as the headstock spindle, so that work already turned may be held in the milling fixture and milled with the aid of cutters gripped in the head.

For cutting threads, an attachment is made

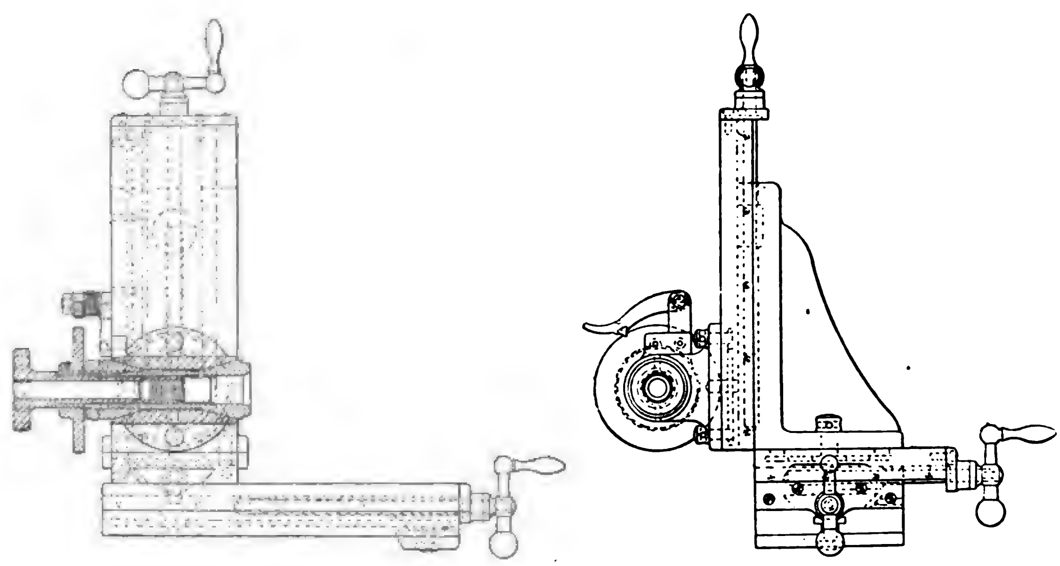


Fig. 141.—Milling Attachment for Bench Lathe.

for grinding, carrying a small spindle, with endlong movement, and rise-and-fall motion for height of grinding wheel. A rapid unlocking device is fitted, whereby the rest can be run back out of the way, for testing the work, and returned again to position, without affecting the setting. Two other small tool post and rest grinders are used, clamped on the slide rest.

The filing attachment, Fig. 140, is worked in jig-saw fashion, by a face plate on the spindle, the plate being shown drawn off a little in the illustration. A pin in this engages with the jaw of the up-and-down rod of the attachment, and serves to reciprocate it as the lathe spindle to bolt to the tee slot on the back of the bed. Change gears from the headstock spindle rotate a hob, and this serves to traverse a small slide, after the fashion of the Fox chasing lathe. Many variations are effected by the change gears, and by substituting another hob of different pitch. Various other fittings as face-plates, centres, &c., are employed, and the countershaft is of special design, to provide means for driving the grinding and other attachments.

With lathes of this type almost any piece of fine mechanical work can be tackled, even though it involves operations never done on lathes in the practice of the larger machine

work. Extreme accuracy is attained, by the precision with which the lathes are constructed. For toolroom use they are very handy, in the production of little cutters of all kinds, as well as for fine mechanisms, gauges, scientific work, gears, models, &c.

Bench Milling Machine.—In fine mechanical work the bench miller plays an important part in conjunction with the bench lathe,—both precision machines of the highest class. The work performed is generally delicate, and although it may frequently be done upon the bench lathe, with the help of suitable attachments, the miller is more convenient in setting up and operating. Fine mechanisms, small tools, gauges, and experimental work are the chief applications, taking the place by milling of much hand filing and scraping, previously employed in such jobs.

An example of a bench miller, the Sloan & Chace, is given in Fig. 142. This is about 16½ in. in total height, and the slide travels 4 in. vertically, 8 in. longitudinally, and 2¼ in. crosswise (to and from the spindle). The top table, provided with a central stud, so that it may be swivelled to an angle, has a graduated base, and can be clamped by the two bolts seen. Cross traverse is given by the screw and balanced handle. The longitudinal movement of the knee is effected by a similar handle on the end of the screw which is seen in section between the vertical vees. The nut in which the screw works has also a rack cut upon one side; and a pivoted and handled sector gearing in this allows of rapid movements of the knee, for certain purposes, the nut being disengaged from the knee while the lever feed is in operation. The knee swivels upon the vertical slide, with a divided base, similarly to the table slide. The up-and-down motion of the entire slide, &c., is effected by the vertical screw seen, driven

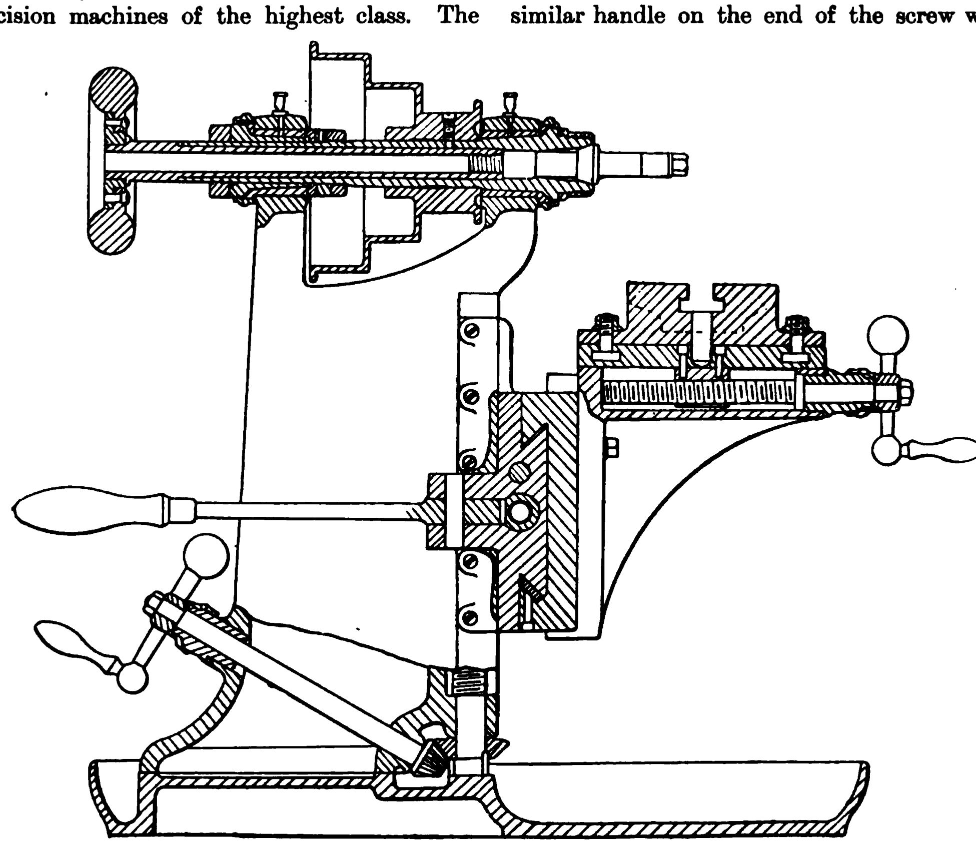


Fig. 142.—Bench Milling Machine.

through bevel gears by the handle and inclined shaft.

The hollow spindle has a spring draw-in chuck, which in the illustration is shown holding a cutter arbor. The fittings attached to the table are a vice and a pair of centres (not shown), comprising head and tailstock, the former being fitted with an index plate. These centres are especially useful for cutting small pinions and gears, and for milling cutters, reamers, taps, &c. The dividing head is fitted with a spring chuck also, for convenience of interchanging mandrels, &c., already held in the bench lathe for operations leading up to the milling.

A type of vertical profile miller is also made for the bench, doing fine work of a few inches only in size. The principle of operation is the same as the regular profilers, a pin and slide, controlled by a former.

Bench Planes.—The jack, trying, and smoothing planes, because these are always kept for use on the bench, while rebates, rounds, and others are not.

Bench Rammer.—A small rammer used on the bench. *See* **Moulders' Tools.**

Bench Vice.—Engineers employ two main forms of bench vice, the ordinary screw, and the instantaneous, the relative advantages of which are a matter of opinion, some men preferring the screw type, notwithstanding that it is rather wasteful of time in operating. The pattern is well known, and need not be illustrated here, but instead we include a drawing of a combination type, the Parkinson, which is both instantaneous and screw, thus combining the advantages of both. Fig. 143 shows the vice in longitudinal section and end view, from which it will be seen that the thread of the screw, buttress shaped, engages in a movable half-nut. The latter is thrown downwards by clasping the lever A to the shank of the screw; on releasing the lever, the spring B throws A back, and pushes the nut up into engagement with the screw, in which state the vice becomes an ordinary screw type. The jaw may therefore be pushed rapidly up to touch a piece of work, and then screwed tightly against it without loss of time. The same device is employed for wood-workers, but the shape of the jaws is different, see Fig. 144, made to fasten underneath the bench.

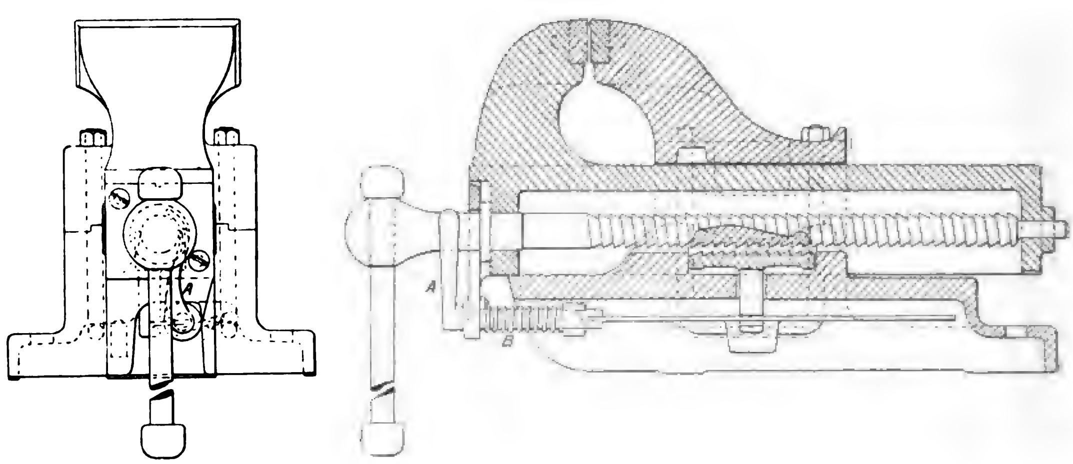


Fig. 143.—Bench Vice. Instantaneous and Screw Types combined. (J. Parkinson & Son.)

Another popular type of instantaneous vice has a cam that pushes forward a block, the teeth of which engage in serrations and draw the jaw along to a certain extent. The chief objection to such an action is that the vice is not suitable for continued squeezing, or forcing, such as is often wanted in fitters' work, for pushing pins, or bushes into holes, &c. Some vices are made with a swivel jaw, to accommodate tapered work in lieu of the use of taper wedges, inserted between work and jaw. Vices are also made with swivel bases, to revolve on the bench, for convenience in handling long work.

For outdoor work bench vices are often mounted upon portable stands, which must however stand firmly, to avoid annoying shake and rocking. Vices range in size from about 3-in. width of jaw to 8-in., opening from about 3 in. to 12 in. *See also* **Machine Vice, Pin Vice, Tube Vice.**

Bench Work.—This denotes work done at the bench as distinguished from that which, owing to its size, character, or position, has to be performed away therefrom. In woodwork and fitting and erecting the building-up of a large structure is not bench work, even though it may be done on the floor or trestles adjacent to a bench. The bench work involved is only the preparation of parts at the bench.

In pattern-making a considerable amount of lathe work is often involved, and the pattern-maker consequently gets occasional intervals at the lathe, so that in the pattern shop, bench work is generally distinguished as opposed to that done at the lathe. Bench work comprises everything that is done thereon, from the marking out of material to the completion of the work, or the stage at which the portions have to leave the bench for fitting together elsewhere.

As applied to moulding it distinguishes work done upon a bench from that on the floor. The latter is unavoidable in heavy and medium heavy castings, and then all mending up and detail work done in the mould has to be performed in a kneeling posture. But a great deal more floor moulding is done than is necessary, very many moulds in boxes no larger than 12 to 18 inches square being so done, which might be just as readily made on a bench, if such was provided, and be only laid on the floor for casting. Brass-moulders have always made the greater portion of their moulds on the bench and there is no reason why all light iron-work should not be so done, with increase in the comfort and health of the workman. The practice of machine moulding is favourable to the growth of bench work. Since men stand at machines, they can easily stand also at benches for hand work. Firms now fit up benches more frequently than formerly, when their work

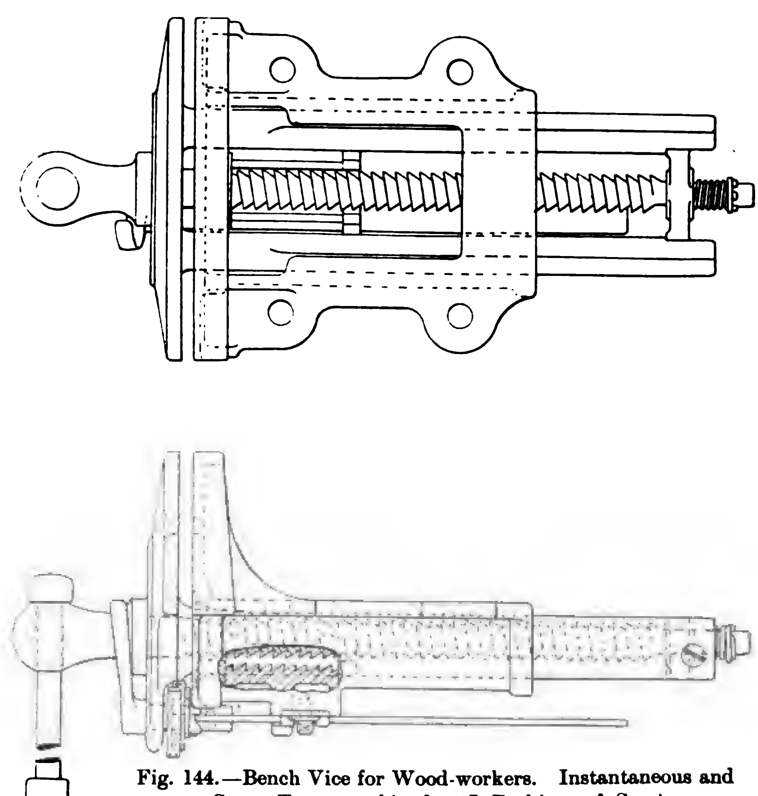
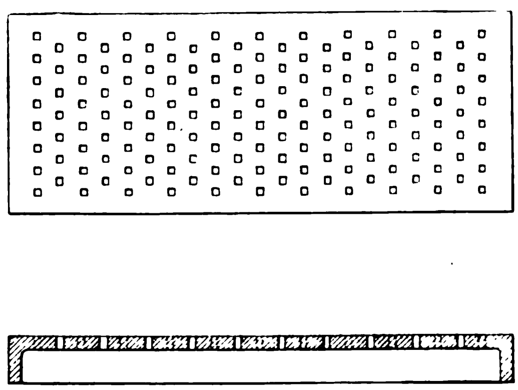


Fig. 144.—Bench Vice for Wood-workers. Instantaneous and Screw Types combined. (J. Parkinson & Son.)

consists largely of light castings. In some foundries the sand floor is dispensed with for a mere casting floor.

Bending Blocks.—The bending block, in the upper part of Fig. 145, pierced with numerous holes, used in the boiler and plating shops, is employed for bending operations, though it is equally adapted for levelling plates, sheets, or correcting sectional forms on; hence also termed a levelling block. The holes are cast for the pur-

pose of receiving pins or bolts, to serve as points of leverage, or for attachments. This block is made in various sizes ranging from 10 ft. to 15 ft. in length, by from 4 ft. to 8 ft. in width.



Bending or Levelling Block.

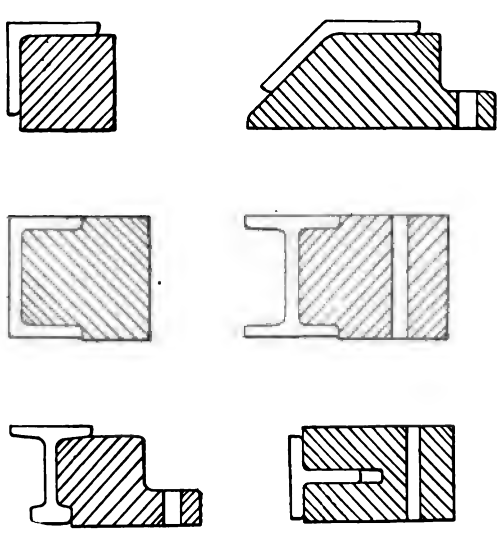


Fig. 145.—Various Bending Blocks in enlarged sections. The bending takes place in horizontal planes.

For long work it is more convenient to cast two or more blocks, and bolt them end to end with planed joints, than to make a single casting. Usually also the top of the plate is roughly planed over with a rough-cutting tool. These plates are used for levelling work upon by hammering. It is a singular thing that massive though they are, and stiffened with flanges, the incessant hammering of the surface causes them to become convex in course of time, so that after a very few years they require to be planed over again.

Between the work done on specialised blocks, and that on the plain bending and levelling block without other aids, there is a considerable volume which is performed by stock blocks of small dimensions on stands. These have the edges made to convex and concave forms, and such blocks may contain a single curved edge

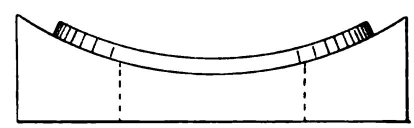


Fig. 146.—Bending Block.

or combine three or four, with straight portions of short dimensions. They are then of general and frequent utility, even though their curvatures and the lengths of the same seldom coincide with proportions and dimensions of the piece of work that has to be done by their assistance. Some typical blocks are shown in the lower part of Fig. 145, from which their utilities can be

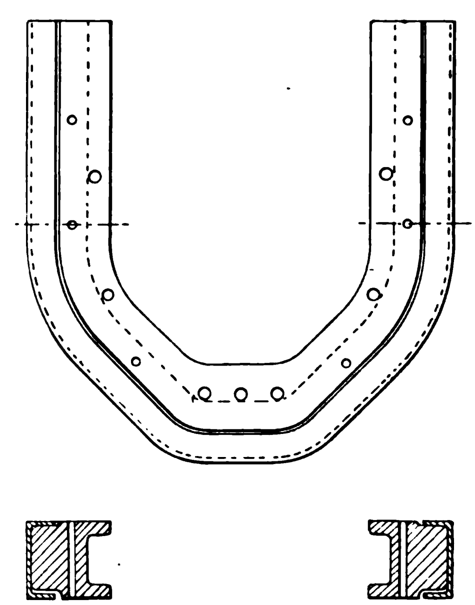


Fig. 147.—Bending Block.

inferred. They are bolted or clamped to the levelling block seen above. Fig. 146 is used for bending a manhole strengthening ring on; Fig. 147 is made for channel iron framings; Fig. 148 is for bending flat bars against chiefly.

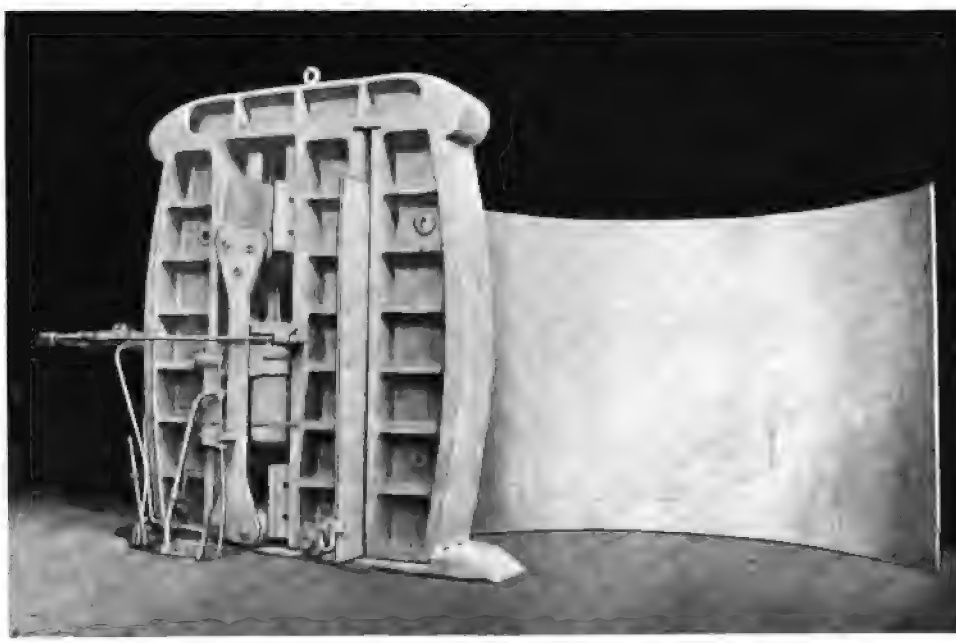


Fig. 150.—Plate Bending Press. (Fielding & Platt, Ltd.)

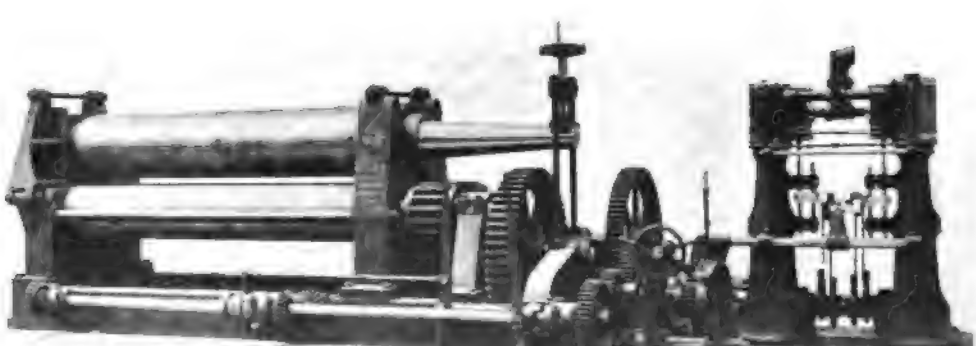


Fig. 152.—Bending Rolls. (Niles-Bement-Pond Co.)
Driven by pair of 40 HP. 8 in. by 10 in. reversible engines. Capacity for plates 2 in. thick and 10 ft. wide.

To face page 150.

The blocks which are set on the anvil resemble these stock types. In many cases they are used on anvil, or bending block, or stand indifferently. Another group which is employed either on anvil, or bending block, is of a special character, for work bent in a vertical plane, and secured with cottars, the block being made for the jobs, and having shapes the exact counterparts of the latter. The cottars pass through straps bolted to the sides of the bending block.

The general ways of making bending blocks are as follows:—A pattern is prepared in wood to the section and curvature required, and moulded from, holes being cast in, by which it is bolted to the main bending block. The small blocks to be used either on the anvil, or on the large bending block have a forged steel stud cast on the bottom to fit one of the holes. Some light blocks are built up of bars or rods, but the majority are cast as just stated. A block may be of such a size to comprise the entire area or surface against which the work is to be bent, as for example a complete ring or disc, or it may in the case of large work only include a segmental portion of the same. In the first case the work would be bent at one operation, and frequently at one heat. In the second it would be done in successive stages, or sections, and at more than one heat.

Bending Machines for Plates.—Heavy plates are preferably bent in a machine which squeezes in successive sections at intervals of about 3 inches. In this, vertical dies, Fig. 149, are used. One die or girder is fixed, the other is movable and is forced against the plate by means of rams and toggle levers. The photo, Fig. 150, Plate IV., shows a type by Fielding & Platt, Ltd., in which the movement is obtained from the ram by means of inclined planes.

Bending Moment.—Is composed of force multiplied by distance, acting upon a section and tending to cause its failure by crushing the fibres in one portion and tearing them apart in another.

If we take Fig. 88 on p. 110 the maximum bending moments upon the sections are as follows:—

$$A = WL \qquad B = \frac{WL}{2} \qquad C = \frac{WL}{4}$$

$$D = \frac{WL}{8} \qquad E = \frac{WL}{12}$$

where W = weight or force, and L = length or distance.

See also examples under **Beam.**

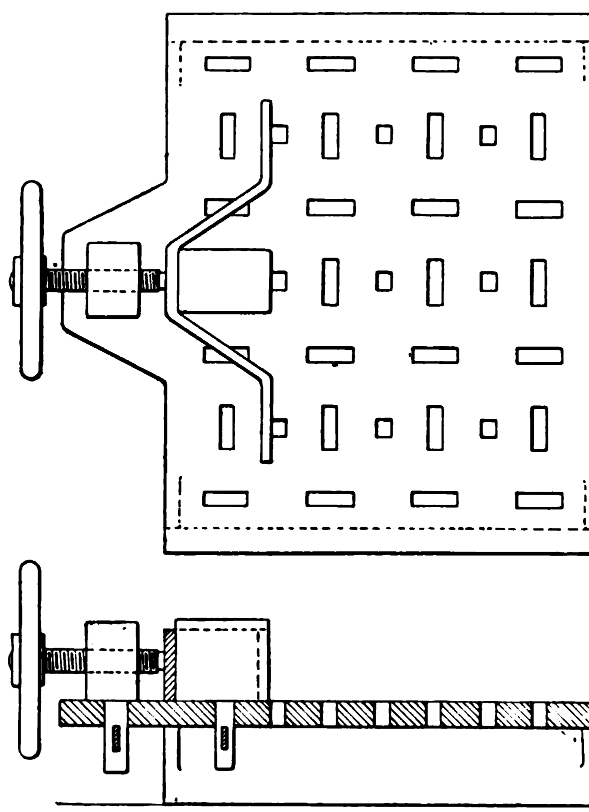


Fig. 148.—Bending Block, fitted with Screw, and Abutment Piece.

Bending Operations.—These fill a large place in the practice of the smithy, boiler, and plating shops, in the fitting, and coppersmithing departments. The subject is too varied and extensive to be dealt with in a single heading. It will be found treated under special heads, as **Angle Iron Work, Bending Blocks, Flanging, Pipe Bending, &c.**

Bending Rolls.—Specifically the machines used for bending plates of iron and steel. They afford the usual means by which this work is

done systematically, though for curving pieces of plate of small dimensions, and also plates of great thickness dies are used in hydraulic machines.

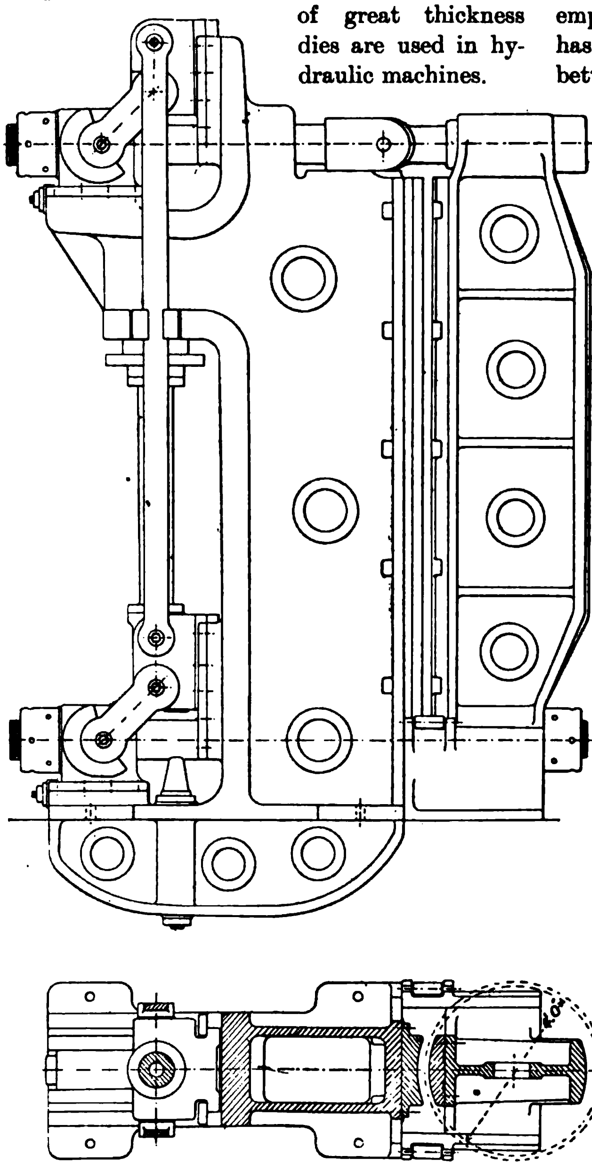


Fig. 149.—Hydraulic Plate Bending Press. (Henry Berry & Co., Ltd.)

There are two broad types of bending rolls, the horizontal, and the vertical, the latter being employed chiefly for very heavy work. This has the advantage of affording facilities for the better handling and movement of plates, which can be slid along edgewise, supported on rollers, and which if very long, do not curve up or down awkwardly, as when bent in horizontal rolls.

The essential action of the common rolls is seen in Fig. 151, A, applicable to horizontal and vertical types, since there is no difference in their principle of operation. There are three rolls, the centres of two being fixed, those of the other adjustable in a plane perpendicular to the plane joining the centres of the fixed ones. By this adjustment curves of different radii are produced, or combinations of curves, by varying the centres during the passage of a plate, the attendant judging of the amount as the work proceeds. The principle is therefore simple. But the practice involves much variation in detail. Around these three rolls the machines built number many designs, see Figs. 152-157, Plates IV.-VII.; light and heavy, with various methods of driving, by belt and gears, by independent engines, and by motors, with different kinds of framings, and adjusting mechanisms, with provision for getting out complete rings, with rolls made of different materials, and supported, or unsupported below. The elasticity of the rolls, evident when rolling thick plates, is the reason for the latter provision.

A fault of all these rolls is that they cannot produce a perfect circle, or circular arc right to the edges, but must leave flats at both entering and leaving edges, due to the separation of the bottom rolls.

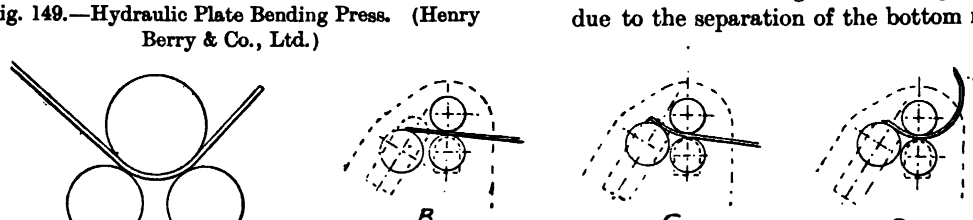


Fig. 151.—Diagrams to illustrate the action of Bending Rolls.

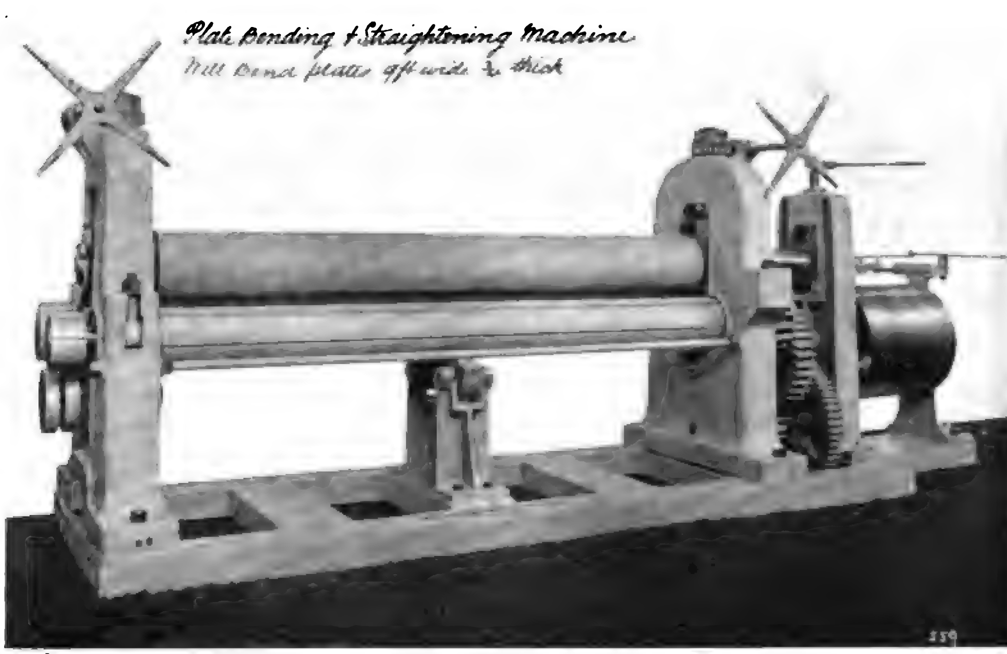


Fig. 153.—Bending Rolls with Supporting Rollers, and Grooves. (Fairbairn Macpherson.)

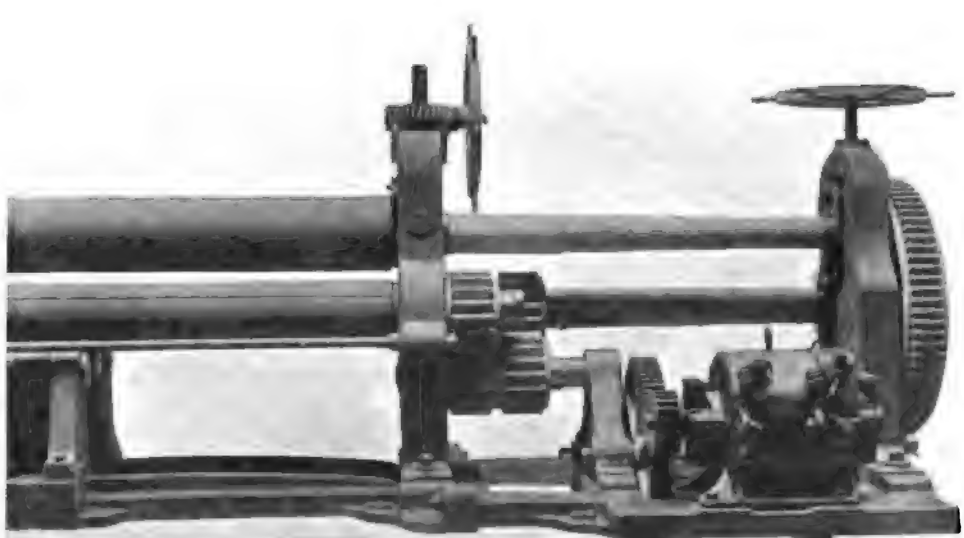


Fig. 154.—Plate Bending Rolls. (Rushworth & Co.)

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There is an improved machine in which the flat edges are avoided by a different disposition of the rolls. Gripping rollers are placed one above the other, and carry the plate simply,

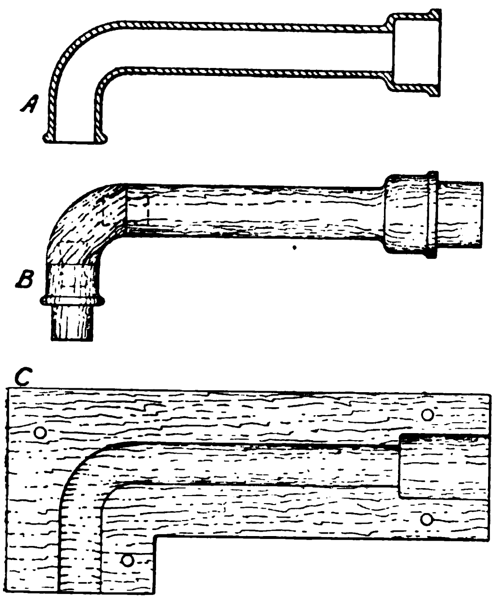


Fig. 158.—Casting, Pattern, and Core Box for Bend.

while the bending is effected by a roll lying outside, and adjustable at any angle as shown by the diagrams B, C, D, Fig. 151, in which successive stages are seen.

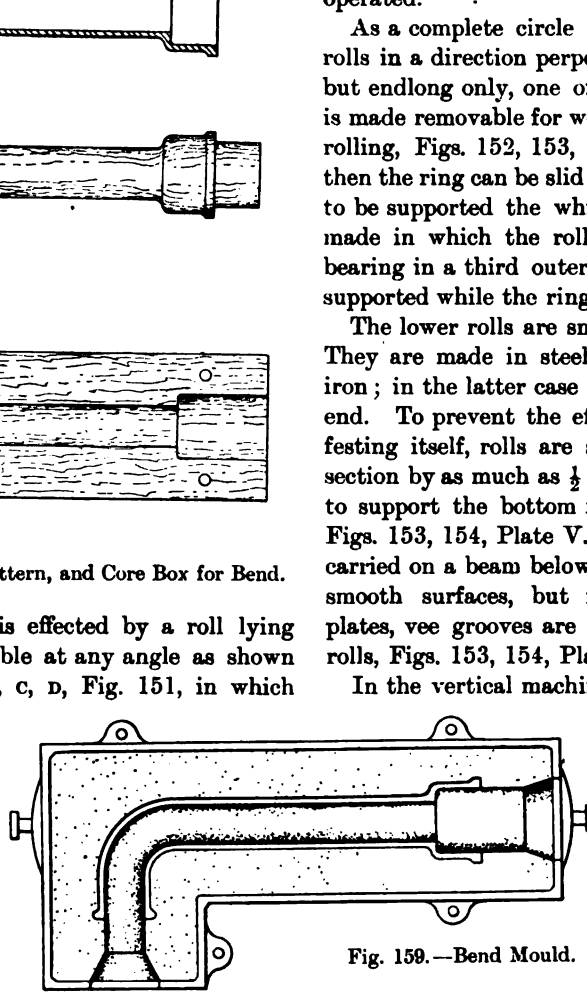
The following is a concise account of the principal variations in the design of bending rolls:—

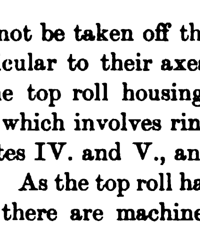
All heavy machines, whether belt or engine driven, are necessarily geared to gain power. Both bottom rolls are gear-driven to run in the same direction. The driving belts are open, and crossed for driving and reversing. The gears are all either situated at one end, or divided between opposite ends, the latter allowing of the employment of larger and more powerful driving gear on the roll ends than the other arrangement. The top roll is adjusted by means of hand screws, with levers, or hand wheels, or in the heaviest machines with worm gear, power operated.

As a complete circle cannot be taken off the rolls in a direction perpendicular to their axes, but endlong only, one of the top roll housings is made removable for work which involves ring rolling, Figs. 152, 153, Plates IV. and V., and then the ring can be slid off. As the top roll has to be supported the while, there are machines made in which the roll is extended to take a bearing in a third outer standard, and is thus supported while the ring is being removed.

The lower rolls are smaller than the top one. They are made in steel, wrought iron, or cast iron; in the latter case the mould is poured on end. To prevent the effect of elasticity manifesting itself, rolls are sometimes cambered in section by as much as $\frac{1}{2}$ inch. A better plan is to support the bottom rolls on friction rollers, Figs. 153, 154, Plate V., having their bearings carried on a beam below. Rolls have generally smooth surfaces, but for working on thick plates, vee grooves are often cut in the bottom rolls, Figs. 153, 154, Plate V.

In the vertical machines the front roll corre-





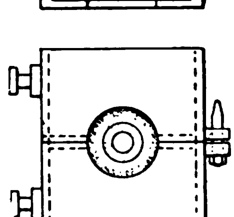


Fig. 159.—Bend Mould.

sponds with the top one of the horizontal type, and the hinder ones are driven positively by gears, as in the bottom rolls of the horizontal kind. When complete rings are rolled, the front roller is lifted out bodily, Fig. 157, Plate VII.

Bend Moulding.—Bend castings are made from full patterns of wood or metal, or they are swept up and moulded from loam patterns. Their cores are rammed in boxes, in green, or in core sand, or they are swept up. Figs. 158-160 illustrate these methods in detail.

Fig. 158, A is a section through a casting of a bend with socket and spigot, and the pattern for it is shown below at B. The straight portions are turned, and the bend is either turned

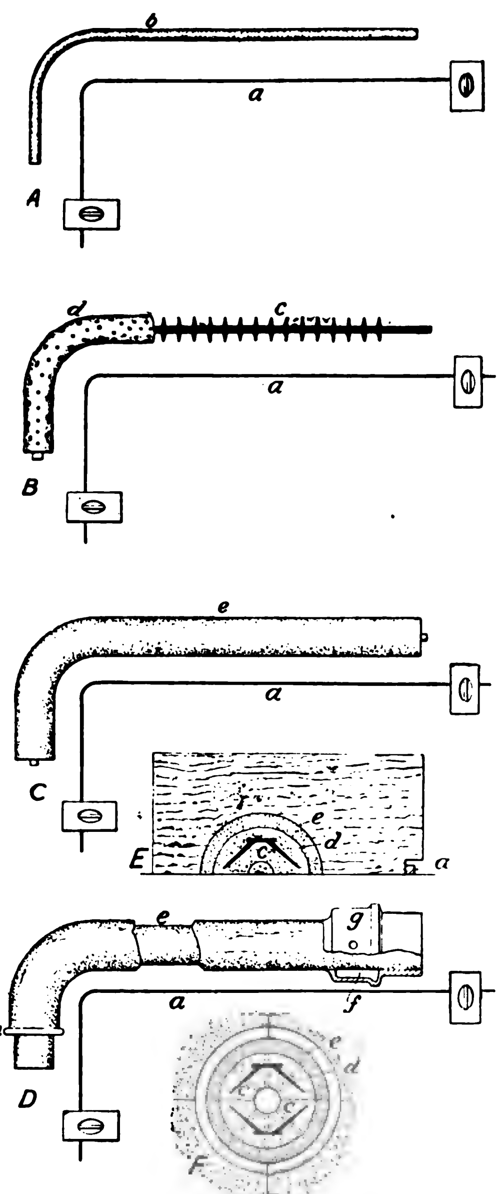


Fig. 160.—Bends in Loam.

separately, or cut to shape by hand. If turned, it is made as a ring of semicircular section, on the face plate, jointed in quarters, and two are thrown away, or else used for another bend.

These are united to the straight lengths with dovetailed pieces. The core box is worked from solid stuff for the smaller patterns, built up for the larger. One-half of a box is shown open at C. If bends are made in large quantities, the box is made of iron, of from $\frac{1}{4}$ to $\frac{1}{2}$ inch thickness, depending on size.

Fig. 159 shows the plan of an open mould for such a bend, cored up, together with end views of the same, showing the main vents of the core.

If such a bend is made in loam, either a guide iron is used, or a core plate, the latter being a rather clumsy method, and involving unnecessary work. The guide iron is shown at *a*, in the group of Figs. 160: A, B, C, D, illustrating successive stages of the work. The guide iron is about $\frac{1}{2}$ inch square, and follows the pipe outline at a distance sufficiently far away to permit of working the strickles. In this case it must clear the largest part of the socketed end. It is retained in place by means of weights laid on the ends, as shown, beyond the farthest point reached by the strickles.

The first thing to do is to lay down a body of loam to form the main core vent through the bend, and into which the smaller vents come from the circumference. This is shown at *b*, in Fig. 160 A. It is daubed roughly with the hands and dried, and parting sand is then strewn on preparatory to the striking of the actual core. The first stage of this is seen in Fig. 160 B. A grid *c* is prepared, to be bedded in each half of the core. It comprises a flat web, and prongs striking out diagonally, as seen in the enlarged sections at E, and F. A body of rough loam *d*, at B, E, and F, with no particular regard to size or shape, is daubed along the entire length of the core. Large radiating vents are made in this, reaching down to the central main vent. This body is allowed to stiffen only, or it may be baked hard, to receive the final coat of fine sieved loam which brings the core up to its finished size *e*. This is done by means of a strickle, see the enlarged Fig. at E, shouldered to be slid along the inner vertical edge of the guide iron *a*, and of such a length between the shoulder and the adjacent edge of the semi-diameter to give the correct radius to the bend.

Thus the plain core *e* for the bore of the bend

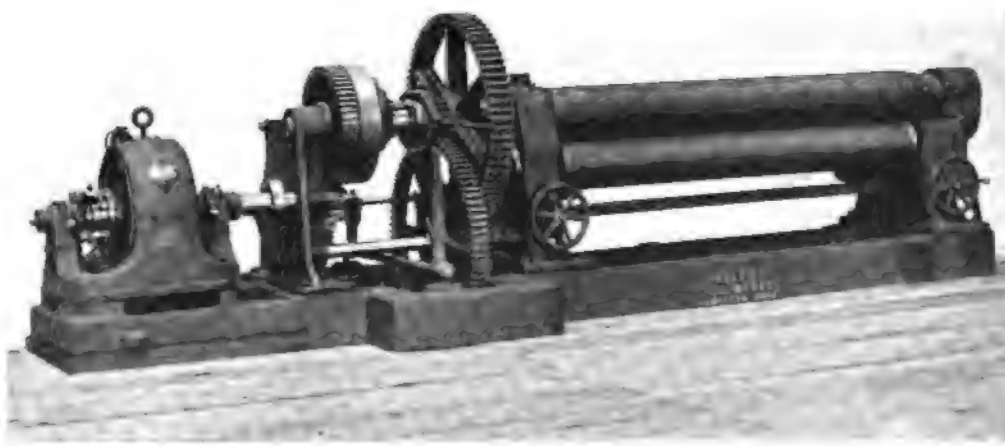


Fig. 155.—Light Bending Rolls. (Niles-Bement-Pond Co.)

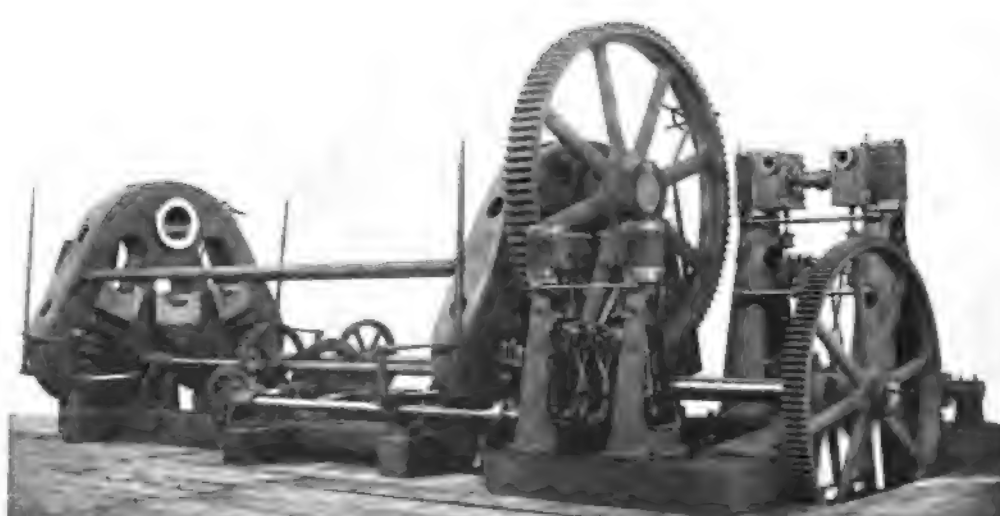


Fig. 156.—Plate Bending Rolls. (Niles-Bement-Pond Co.)
Feed Rolls above one another, Bending Rolls at sides.

is obtained, but not the enlarged portion at *f*, for the socketed end. This is now swept on with another strickle worked from the same guide iron, and the shoulder of the socket is dressed round square by hand after the loam has dried. Or a strickle can be used working longitudinally.

From this stage there are two methods open in making loam bends. One is to strike the pattern on the core just made as at D, or to make a separate and distinct pattern in loam. Generally if one casting only is wanted, as for odd and special sizes, the first method is adopted. But if there are several the second is preferable. In the first case the mould is taken from the loam pattern, and then the pattern "thickness" is stripped off, leaving the core ready for use. In the second, as many cores are made as there are castings required, but one loam pattern only.

The "thickness," which of course equals the thickness of metal in the casting, is laid on over plenty of parting sand, and swept as at D with a strickle working from the guide iron, the position of which is not altered. So that the shoulder of the pattern strickle has to be shorter than that of the core strickle by just the amount of the "thickness."

This brings us to the completion of the pattern body. The socket is made by three different methods. The quickest and neatest of these is to get an iron pattern socket *g*, at D, from the stores, as used for screwing on wooden patterns, and lay this on the loam body. It cannot be fastened in any way, beyond pressing it on tightly in the position which it is to occupy.

Another plan frequently adopted is to strike the socket up in loam on a revolving body, carried on a bar, the body being of the same diameter as that of the loam pattern. The socket is sawn in two, slipped off, and then nailed on the loam pattern. A third plan is to fit a templet ring of iron on the pattern, and use this as a guide for sweeping the socket with a strickle working longitudinally.

The bead on the spigot end is made of a strip of lead *h*, bent round and nailed on. The pattern is finished by giving it while warm a coat of tar. Over this a coat of shellac varnish is sometimes laid. F is a section through the core and mould showing the chapleting.

When small bends are made in large quantities they are moulded from iron patterns, and the cores rammed in green sand in iron boxes. The grid shown in these figures is not used, but a plain grid with counterbalanced ends.

Bend Pipes.—Are used to cause a diversion in the direction of straight piping. They are termed "bends" when struck with a radius not very small, the term "knees" and elbows is applied to those bends which have either an exceedingly small radius or a keen angle. In hot-water fittings the term "elbow" is often applied to a true bend. The term "round elbow" denotes one which is keen on the inner angle but convex on the outer.

The angles at which bends connect their pipes are often denoted by degrees, or by fractions of a circle. Thus a bend making connections at right angles is one of 90° or a "square" or a "quarter ($\frac{1}{4}$) bend." Bends are termed $\frac{1}{4}$, $\frac{1}{6}$, $\frac{1}{8}$, $\frac{1}{12}$, $\frac{1}{16}$ when they would make four, six, eight, twelve, and sixteen respectively to the circle. In gas, steam, and water fittings these are also called "springs." The terms "square" and "obtuse" denote bends for rainwater, which are of right and obtuse angles respectively. In hot-water work, common or square elbows and $\frac{1}{8}$-circle elbows are used, and the smaller and larger sizes are denoted as 1st, 2nd, and 3rd radius.

Generally bends are of circular cross-section, but in rainwater fittings they are also made rectangular. The small bends and their fittings for gas, steam, and water are made of wrought iron or steel tube, but all others are cast.

The methods of union of bends are the same as those of pipes, including sockets, spigots, and flanges in ordinary cast work, sockets and spigots in rainwater work and hot-water pipes, and screw threads for gas, steam, and water.

Bends of small radius and knees cause loss of head. The formula given by Weisbach for calculating the loss is:—

Additional head in feet

$$= \cdot 131 + 1\cdot 847 \left(\frac{r \text{ in feet}}{\text{R in feet}}\right)^{\frac{7}{2}}$$

$$\times \frac{\text{square of velocity in feet per second}}{64\cdot 4}$$

$$\times \frac{\text{central angle in degrees}}{180}$$

in which r = the radius of the pipe, and R = the radius of the axis of the bend; $\frac{7}{2}$ means the square root of the seventh power.

Bennis Stoker.—*See* **Mechanical Stokers.**

Bent Gouge.—A gouge curved in the longitudinal direction, which renders it valuable for core box work.

Bent Lever.—*See* **Levers.**

Berdan Pan.—A form of pan used for grinding and amalgamating the materials crushed by battery stamps. It is an annular pan with its axis set at a considerable angle from the vertical, and rotated by bevel gearing at the top of a shaft. Heavy cast-iron balls are placed in the pan which grind the material as the pan rotates.

Berm.—The ledge at the lower part of a sloping bank.

Bertrand-Thiel Process.—This is one of the inventions designed to expedite the work of the open-hearth steel process, both acid and basic. It yields a larger percentage output than the ordinary open-hearth process. As much iron is reduced from the ore employed in the furnaces, this more than compensates for the loss of metalloids. Pig iron of greater range of composition can be treated by the Bertrand process. The mixer is no essential part of the method, but it is beneficial to it in a similar way to the benefits it confers on all other processes employing liquid pig iron, *i.e.*, yielding a much more uniform metal for treatment.

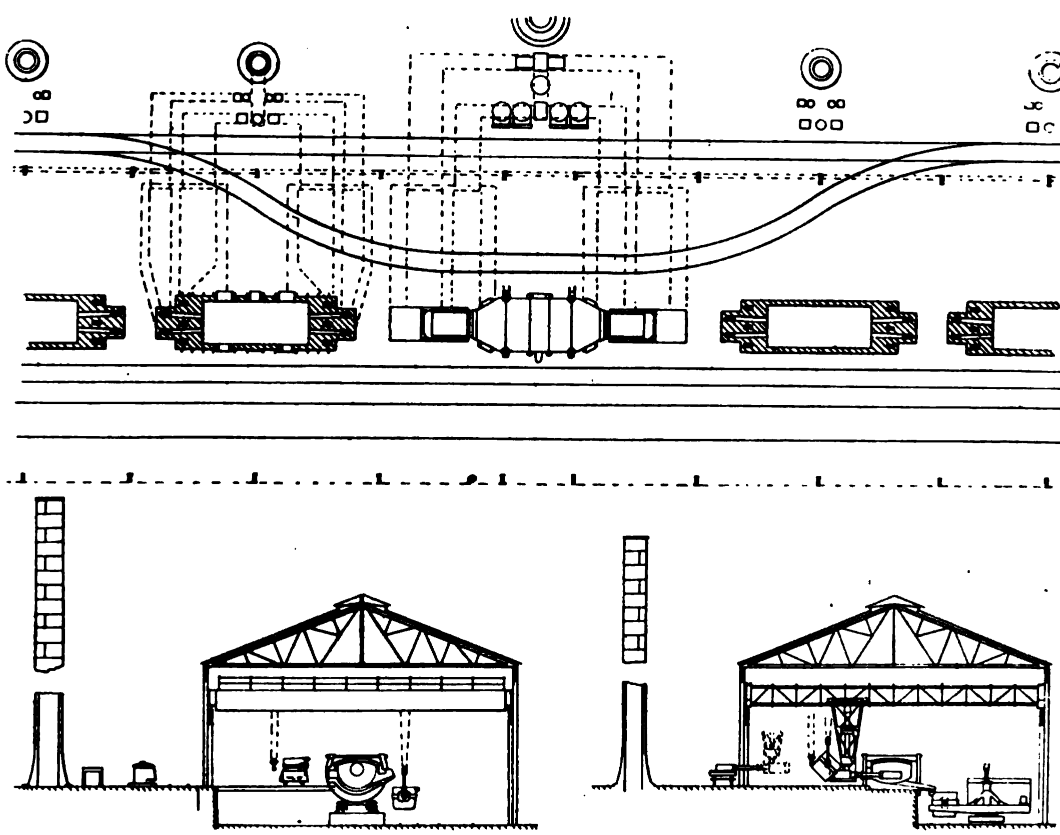


Fig. 161.—Plant for Bertrand-Thiel Process. (By John Darby, Esq., at Brymbo.)

Two open-hearth furnaces are used in combination, termed the primary and secondary, see Fig. 161, in which the open-hearth furnaces are arranged on each side of a mixer. The metal from the blast furnace is poured into the mixer, which may be either gas-fired or not. Ore and limestone are charged into the primary furnace, and when heated the

Fig. 157.—Vertical Bending Rolls. (Niles-Bement-Pond Co.)

To face page 156.

metal from the mixer is transferred to the primary furnace. Here the whole of the silicon is removed, most of the phosphorus, and a small proportion of the carbon. Compared with the secondary furnace it is a low temperature reaction. In from two to three hours the charge without the highly phosphoric slag is transferred to the secondary furnace by means of a ladle. This furnace contains highly heated scrap, iron ore, and lime—the result is a vigor-

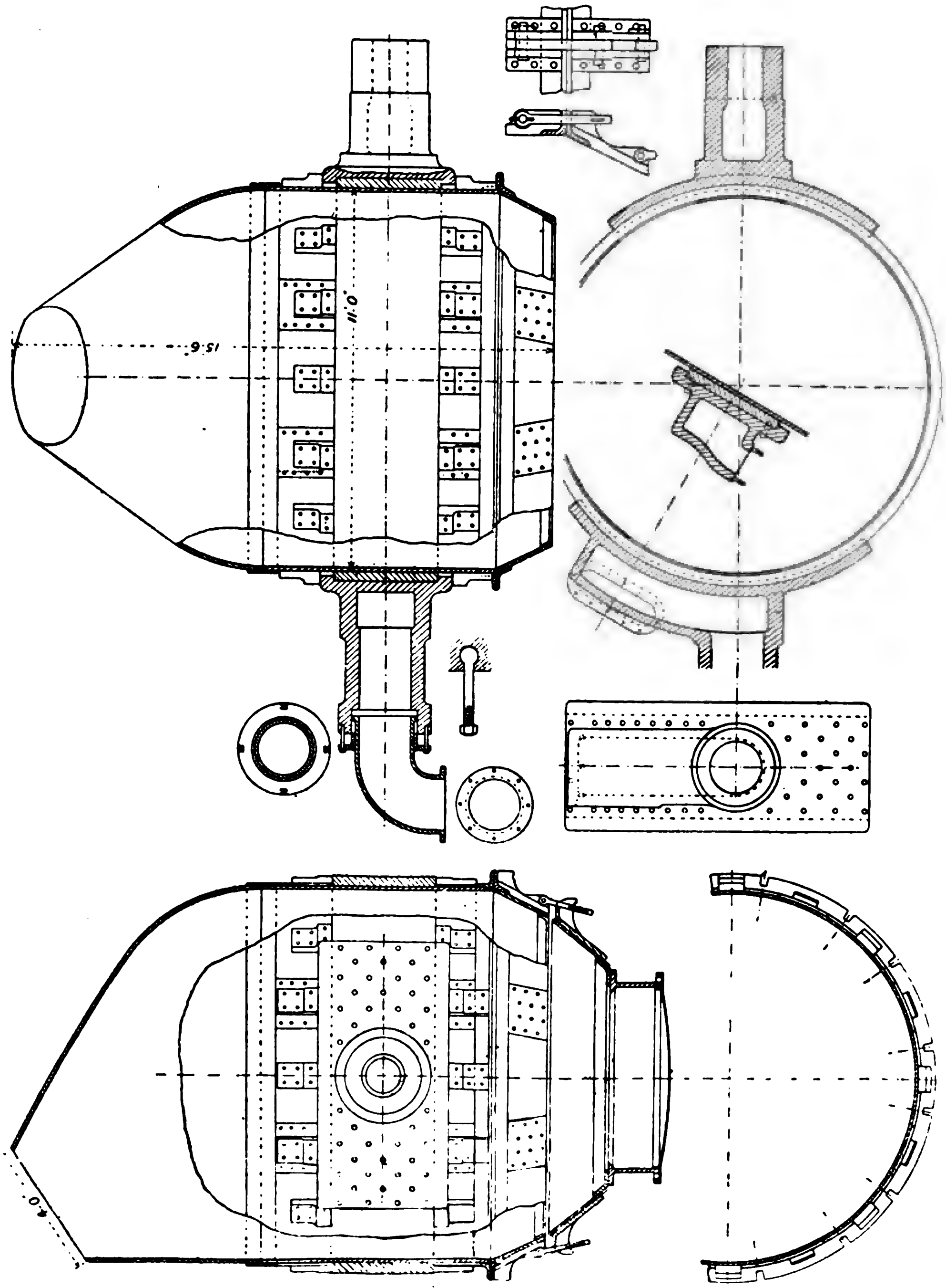


Fig. 162.—Details of 15-Ton Converter. (Barrow Hematite Steel Co.'s Works.)

ous reaction, and the carbon is rapidly removed. As soon as the charge has boiled down to the requisite percentage, the last traces of phosphorus are removed and the carbon reduced to the proper amount, when the metal is ready to be poured into ingot moulds. From seven to ten 20-ton charges per day of twenty-four hours are worked by this method.

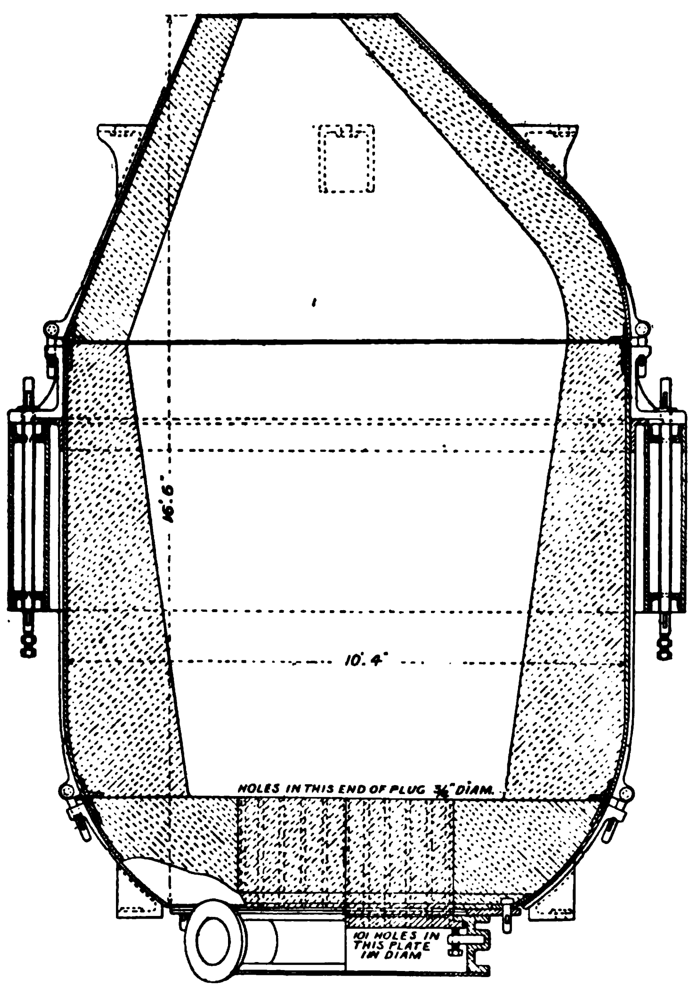


Fig. 163.—10-Tons Basic Converter. (North-Eastern Steel Co., Ltd., Middlesbro'.)

Bessemer Converter or **Convertor**.—The pear-shaped vessel in which steel is made by this process.

The converter was designed by its inventor substantially as now made. The original form was fixed, having an inlet at the sides, but it was soon superseded by the tipping type carried on trunnions, and having air inlets at the bottom. The objection to the first experimental vessel, put up at St Pancras, was that the blast did not penetrate the metal, but escaped too rapidly and cut away the lining. The tipping type passed through a few modifications until the first converter of the present general form was put up at the Bessemer Works in Sheffield.

The converter of to-day is built of mild steel plates, lined with silica bricks, or ganister, and generally having a neck or throat inclined at an angle of about 30° to the body. When the vessel is in the vertical direction, the neck may be directed towards an open-hooded chimney, into which the sparks and flame are discharged during the blow.

A trunnion ring, Fig. 162, forms a belt round the body of the converter, being built up of steel plates, or cast. One of the trunnions is hollow, to receive the blast, which is conveyed thence through a pipe to the tuyere box. The other is solid, and receives a pinion which gears with a rack forming a prolongation of the ram of a double acting hydraulic cylinder, by which the converter is turned up and down.

The original converters were all riveted to form the bottom in one with the body. But the rapid wear on the tuyeres, which caused frequent stoppage for repairs, led Mr Holley to design the movable bottom, attached to the shell with lugs and cottar bolts. The lining of the bottom, containing the tuyere holes is generally worn away in from twelve to fifteen blows, while the lining of the body lasts for several months. The removable bottom can be renewed within an hour. The bottom, containing the tuyere

holes, rests on the blast box, see Fig. 163. The tuyeres are of fire-clay, each pierced with from twelve to eighteen holes, from ⅛ in. to 1 in. in diameter. Any tuyere can be removed independently of others.

The lining of the converter, Fig. 163, is ganister, containing from 85 to 90 per cent. of silica. It is ground coarsely, with, or without a little fire-brick, and mixed with water and rammed in between the converter and a wooden core. Sometimes the lining is a single thickness of fire-brick, and a thinner coat of ganister. Tar is sometimes substituted for the water, and this when dried forms an anhydrous cement of solid carbon. The ganister lining is dried, and heated before the charge is introduced. The capacities of ordinary converters range from 6 to 15 tons of pig iron. An 8-ton converter measures about 8 ft. 4 in. within the casing, or 6 ft. 10 in. inside the lining.

Of late years there are two tendencies observable. One is towards an increase in the number of large converters, the other a growing employment of small "Baby Bessemer" converters for foundry work. These are used in England, Germany, Sweden, and the United States. Some are fixed, others tilt, and successful results are obtained in converters having a capacity of 10 cwt. only. Their value lies in the production of small steel castings. The difficulty met with is to retain a sufficient degree of heat to render the metal fluid enough for casting. But good results are attained by special devices. In the Walrand Legénisel process this is obtained by introducing melted ferro-silicon after the oxidation of the carbon, and effecting a short after-blow. In the Robert, the tuyeres are introduced at the side horizontally, but inclined to give a rotary motion to the bath of metal, bringing all parts of the metal under its action. An excess of air is employed, burning the carbon monoxide, with increase of temperature. In the Tropenas process the blast acts on the surface of the metal. The converter bottom, Fig. 164, has the sectional shape of a truncated cone, so offering a large upper surface for oxidation. There are two rows of tuyeres, an upper and lower. The lower rows are "tuyeres of reaction" because the air blown through them comes on the surface of the metal. The gases that come off as the result of oxidation are burnt by air brought through the upper row, or "tuyeres of combustion." In this, as in other small converters, the blast pressure is very much less than in the large types, being only from 2 lb. to 4 lb. per square inch compared with 20 lb. to 25 lb. in the big ones.

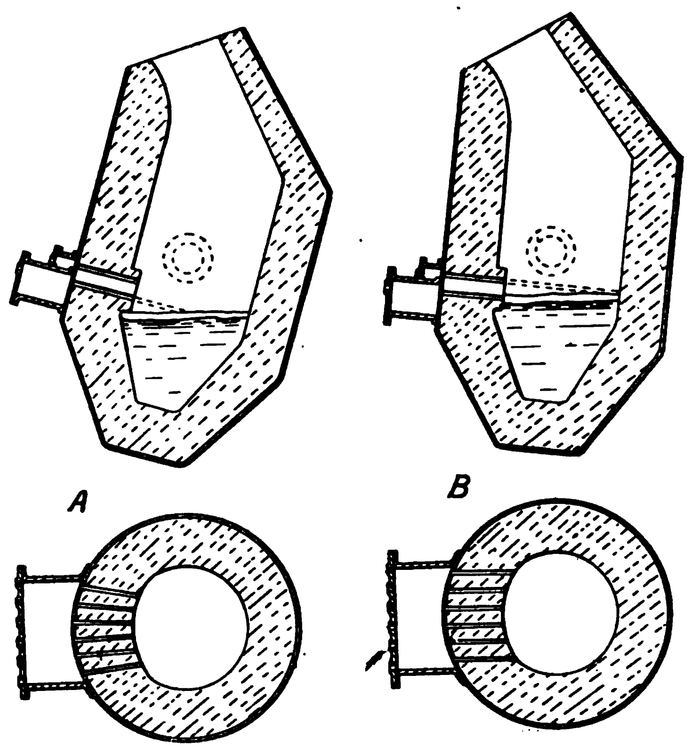


Fig. 164.—Tropenas Converter.
A. **Position at commencement of blow.** *B.* **Ditto at second period of blow.**

These baby converters have the advantage that several blows can be obtained in a day in a foundry. In the absence of a large plant of open-hearth furnaces, or Bessemer converters, the steel from several blows can be collected in a ladle, and castings of several tons weight be produced without loss of fluidity.

Bessemer Cupola.—*See* **Cupola Furnaces.**

Bessemer Pig.—The quality of pig which must be used in the acid process, the chief essentials of which are almost entire freedom from phosphorus, sulphur, and copper, and that it must be of the grey quality. Such a typical pig will contain from 3·5 to 5 per cent. of carbon, 2 per cent. of silicon, 1 per cent. of manganese, with not more than 0·06 per cent. of phosphorus, and 0·06 per cent. of sulphur. The most important point is that phosphorus and sulphur must not exceed the amounts named, as neither of them are removed in the acid process. But silicon and manganese may vary considerably, the first between 1 and 2·5 per cent., and the second between 0·5, and 2 to 2·4 per cent. Much might be said about the effects of varying the proportions of these elements.

The temperature of the metal depends mainly upon the amount of silicon, hence a small quantity of this element, with large charges, and rapid succession of blows will maintain as much heat as a larger one under the contrary conditions. There is less waste of iron in the form of ferrous silicate. But if silicon is kept too low, the metal will not be dead melted, and will be liable to set. Using a large percentage of silicon, a larger volume of oxygen will be required, and the wear and tear of the lining be greater.

Manganese is essential both in the finished product and in the pig. If a pig is low in manganese, the element must be introduced in the ferro-manganese alloy as is usual; but if high in that element, it is possible to make steel without such additions, as has been done in Sweden. Manganese exercises a beneficial effect during the period of the blow. It is a generator of heat. It combines with excess of oxygen in the blast, its oxide unites with the silica produced by the oxidation of the silicon, producing fusible slags. These however exercise a corrosive effect on the siliceous lining. Manganese protects the bath of metal from oxidation, and prevents deterioration of the metal, which would occur by the presence of ferrous oxide, or an excess of oxygen. Its slag also tends to reduce the sulphur in the metal. In the finished product manganese is necessary to prevent red shortness.

The effects of these elements can never be considered alone, since they act and react on each other, hence the wide field for variations in Bessemer practice. National differences in practice are largely explained by the variations in the ores used, since with every important change in percentage composition, methods must be varied, duration of blows, frequency and volume of charges, hot, or cold melting, and so forth.

In the basic process, the pig of which is highly phosphoric, 3 or 4 cwt. of lime per ton of metal are introduced into the converter before the metal, and this with the dolomitic lining, and the after-blow is the difference between the basic, and acid working. The silicon in the basic process is better if not exceeding 1 per cent., though pig with 2 per cent. is often used.

Bessemer Pit.—*See* **Bessemer Plant.**

Bessemer Plant.—A typical plant comprises two converters, a casting pit, a crane or cranes, a ladle, a cupola, or cupolas, ingot moulds, and sometimes now an ingot stripper. Such a plant is subject to much variation in regard to the details of its mechanism, and its general arrangements, and the designs which find favour at present differ in several respects from those of a few years ago, having for their object economy of time and increase in output.

In the older plants which remain in use in many works, the two converters are placed on opposite sides of a deep casting pit of circular shape in plan. In the centre there is an hydraulic casting crane, which rises and lowers, and is revolved, the horizontal jib carrying the ladle. The latter is filled with the metal from the converter and slewed round at the proper height over the ingot moulds in succession, which are poured from the bottom of the ladle. The cupolas are generally adjacent to the pit and comprise those for melting the Bessemer pig, and for the speigeleisen. One cupola often suffices for the latter service, but from two to four are required for melting the pig.

Generally the lifting of the ingot moulds by the crane allows the ingot to "strip" or drop out. But if the moulds are old and rough such will not always happen, hence the ingot stripper has been designed to pull the mould up and hold

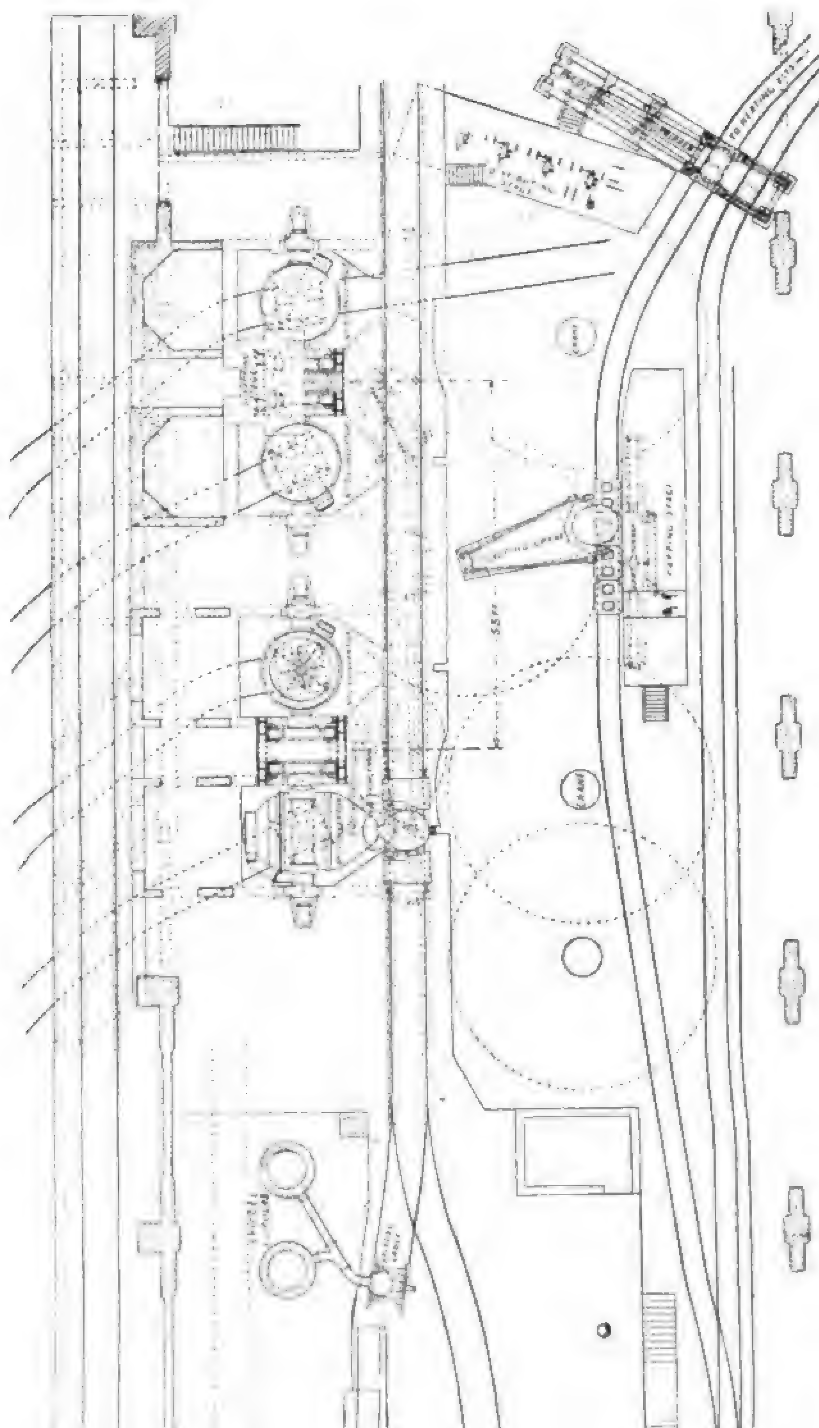


Fig. 165.—Modern Bessemer Plant. Plan View. (Barrow Hematite Steel Co.'s Works.)

the ingot down. These are as yet only used to a limited extent.

In the later Bessemer plants more room is given than the circular pit flanked by two converters affords, and the men are further removed from the molten metal. The converters are placed in line on one side of the pit, and the latter is made much shallower, sometimes abandoned. A pair of converters are served by a single crane of radius sufficient to reach the mouths of the converters at the rear and the ingot moulds at the front. In order to increase the range of operations beyond that which the radius of a single jib affords, the practice is sometimes to utilise two cranes, one to receive the metal from the converters, the other to take the metal from the first and pour it into the ingot moulds.

Sometimes a straight pit is employed parallel with the converters. Or the pit is dispensed with and the metal carried on bogies on rails, Figs. 165, 166, and the moulds themselves are pushed along as fast as they are filled from the fixed crane that receives the ladles of metal. The various portions of Bessemer plant will be found treated under their proper heads, as **Bessemer Converter, Casting Ladle, Ingot Crane, Ingot Mould, Ingot Stripping.**

Bessemer Steel.—The "mild steel" or "ingot iron," extremely low in carbon made by the Bessemer process was probably second to no other invention of the nineteenth century. About 17 millions of tons are made annually by this process, yet in 1855 when Bessemer's now historic paper was read at the meeting of the British Association at Cheltenham, it was not even printed in the "Transactions" of the Association. Bessemer himself while at breakfast at his hotel heard an iron-master say to a friend, "Do you know that there is somebody come down from London to read us a paper on *making steel from cast iron without fuel.* Did you ever hear of such nonsense?"

The first Bessemer works were established in Sheffield in 1858. Firms soon bought the patent rights, Holley came from America and paid £10,000 for the patent rights for that country. In the course of three or four years the new steel was being sold at from £40 to £50 a ton, though its prime cost was less than £10. In the course of fourteen years the partners in the Bessemer firm took out as much as fifty-seven times the original capital embarked in the business. By 1866 Bessemer was receiving about £500,000 a year from his process, and his invention has made the fortunes of many others, and increased the riches and the resources of the world.

Bessemer's attention was first drawn to the production of steel in consequence of permission

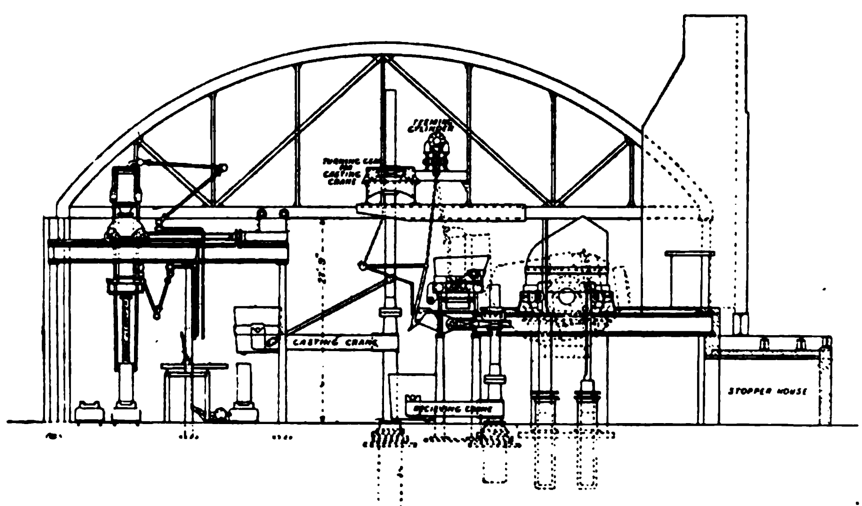


Fig. 166.—Bessemer Plant. Sectional Elevation. (Barrow Works.)

he received from the Emperor Napoleon III. to erect a furnace for producing guns of cast iron, hardened by the addition of steel. He thought that the temperature of the furnace might be increased by forcing a draught of air into it with a fan. In the course of his experiments he tried the effect of bringing a blast of air down a fire-clay pipe into a crucible of melted iron, with the result that 10 lb. of cast iron were converted into malleable iron in the course of half-an-hour. This was the germ of the Bessemer converter, which passed through many experimental stages, ending in the hinged pear-shaped vessel. He was astonished at the phenomena of oxidation that went on. "The apparatus became a miniature volcano in a state of active eruption. All this was a veritable revelation to me, as I had in no way anticipated such violent results." The first patent was taken out 7th December 1855, for the manufacture, not of steel, but of malleable iron.

The *rationale* of the Bessemer process is as follows:—The molten cast iron in the converter contains impurities which must be got rid of, or their proportions regulated in order to produce mild steel. These are carbon, silicon, sulphur, phosphorus; their oxidation takes place in successive stages, which are well marked, and the heat generated is sufficient to maintain the bath of metal in a fluid state until the process is completed. The regulation of the degree of oxidation would be practically impossible, and therefore the practice is to burn out all the carbon, and then add the slight percentage required in the form of an alloy,—speigeleisen.

In two respects Bessemer's process had been anticipated; in one by James Nasmyth, 4th May 1854 (1001), consisting in the employment of a current of steam discharged from the nozzle of a pipe bent downwards to the bottom of a bath of molten metal. The decomposition of the steam would supply oxygen for the burning up of the carbon in the iron, and the agitation produced should supersede the work of the puddler. Nasmyth heard Bessemer's paper read at Cheltenham, and though regretting the fact that his own process was superseded, he abandoned it in favour of Bessemer's. The latter offered him a one-third share in the value of his patent, which was courteously declined. The other was by Robert Mushet, 22nd September 1856 (2219), consisting in the addition of speigeleisen to decarbonised molten iron.

The stages of the Bessemer process are as follows:—

The molten pig iron is charged into the converter direct from the blast furnace, or from a cupola. The blast is then put on, and the converter turned into the vertical position. The first stage commences, and lasts about five minutes. During this period the graphitic carbon passes into the combined form, the silicon is oxidised to silica, and this combines with ferrous and manganous oxides, producing slags composed of silicates of iron and manganese. This stage is marked by the ejection of large quantities of sparks, and the burning of graphite. The flame is only faintly luminous, of a slight yellowish red tint, and small in volume. The temperature rises rapidly, due chiefly to the oxidation of silicon, and during the second stage, or "boil" the flame becomes of a dense yellow colour, due to the burning of carbon monoxide, CO, and increases in volume. The metal is violently agitated, and slag and sparks and burning iron are ejected. Large quantities of carbonic acid are evolved, due to the oxidation of the carbon in the pig. The pressure of the blast now falls from 20 or 25 lb. to 15 or 20 lb. per square inch. This stage lasts from about seven to ten minutes. The third or "fining" stage is a period of comparative quiescence. The flame diminishes, and becomes less brilliant, and the shower of sparks lessens. In the reactions which go on, the silicon and manganese are oxidised before the carbon. In about twenty minutes from the commencement the decarburisation is completed, indicated by the "dropping" of the flame. Then the converter is turned down into the horizontal position, and the blast shut off. From 7 to 10 per cent. of molten speigeleisen, or a lesser amount of ferro-manganese is then introduced to recarbonise the metal, with a resulting reaction, and the pouring forth of a roaring jet of flame from the mouth. The metal is allowed to stand a few minutes, and is then poured into ingot moulds.

The term "acid" and "basic" processes refer to the presence of phosphorus, which, if beyond

the merest trace, wholly prevents the manufacture of a ductile steel. The term acid was due to Professor Tunner, and refers to the non-metallic siliceous lining ganister, used in all the early converters, the presence of the silica in which prevented the elimination of phosphorus. In the acid process all the phosphorus and sulphur present in the pig remain in the steel, and as there is a loss of pig iron due to oxidation during the process, the percentage in the steel is really rather greater than that in the iron. The silica in the acid lining has stronger affinity for the oxide of iron in the slags than phosphorus has. The silica therefore displaces P_2O_5 immediately on its formation, and the latter becomes reduced to phosphorus and oxygen, and the former at once returns into the metal. Hence with acid linings the employment of non-phosphoric iron is absolutely essential. How this fact hampered and well-nigh wrecked the fortunes of the early Bessemer process is hardly appreciated by the present generation. It engaged the attention of many workers at a time when the present large importations of pure Spanish ores had scarcely began.

Acid steel is made in large quantities from pure ores, but the basic process permits of the utilisation of highly phosphoric ores, which spelt disaster before that process was invented. M. Grüner seems to have been the first to point out that the presence of silica in the ganister lining explained the non-elimination of phosphoric acid, and assigned 30 per cent. as the quantity of silica in the slags sufficient to ensure the return of phosphorus to the iron. Lowthian Bell in 1875 tried adding oxide of iron to the charge, but the resulting action was too violent, and the converter lining became corroded. In 1872 Snelus nearly struck the secret of success, for he tried a lining of lime, but did not pursue the experiments. In 1878 Sydney Thomas and Percy Gilchrist created an epoch in steel making, by publishing the results of their experiments with a basic (metallic) lining, composed of two parts of lime to one of oxide of iron, the "Blue Billy" of the puddlers, and making a basic addition of lime to the charge. The basic slag which resulted held the phosphoric acid, and prevented the return of the phosphorus to the iron. At the same time a large proportion of the sulphur was removed. Magnesian limestone (dolomitic lining) is now used in the basic process. The operation is conducted in the same way as in the acid as far as the third stage, or "drop," following which there is an "after-blow," during which the phosphorus is attacked, combining with the lime in the charge to form a stable phosphate of lime. Phosphate of lime is not decomposed by metallic iron at the temperature of the converter. An excess of phosphorus is beneficial, because by its oxidation it adds to the calorific intensity of the blow. The following tables by Mr Stead, and Mr Richards respectively show the gradual elimination of the impurities during a basic Bessemer blow.

Analyses of Metal taken at Different Periods of the Basic Bessemer Process (Stead).

Period from Commencement.	Carbon.	Manganese.	Silicon.	Sulphur.	Phosphorus	Copper.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Fluid iron - - - -	3·57	0·71	1·70	0·06	1·57	Trace
3 minutes - - - -	3·68	0·62	0·81	0·06	1·60	„
6 „ - - - -	3·40	0·56	0·28	0·06	1·63	„
9 „ - - - -	2·35	0·38	0·05	0·05	1·43	„
12 „ - - - -	0·88	0·27	0·01	0·05	1·42	„
14½ „ - - - -	0·07	0·12	Trace	0·05	1·22	„
16½ „ - - - -	Trace	0·10	Nil	0·05	0·14	„
16 „ 35 seconds -	Trace	Trace	Nil	0·05	0·08	„

FLUID METAL (RICHARDS).

Minutes after Commencement of Blow.	Carbon.	Silicon.	Sulphur.	Phosphorus.
	Per Cent.	Per Cent.	PerCent.	Per Cent.
0	3·5	1·7	·05	1·50
3	3·6	·8	·05	1·60
6	3·40	·28	·05	1·63
9	2·40	·05	·05	1·43
12	·09	·01	·05	1·42
14½	·075	·00	·05	1·20
16½	·00	·00	·05	·08

Best or **B.**—The number 3 quality of wrought iron, which is the poorest, excepting merchant bars.

Between Centres.—Denotes the holding of work in lathe, grinding, milling, planing, and shaping machines, at both ends, as distinguished from that gripped by face plate or chuck at one end only. The use of the second centre becomes necessary when work overhangs considerably, although in the case of turret work pieces of several feet in length are held at one end only, the cutting tool being formed in a box so as to support and steady the bar during turning.

Bevel.—The bevel, or bevel square is in constant use by both wood and metal workers for the testing of angles. The instrument comprises a stock, and an adjustable blade which can be clamped at any required angle. Fig. 167 shows three types, A the ordinary pattern used by wood-workers, B the universal bevel, which may be employed in innumerable ways; C is an improved type, with an offset blade, by which very flat angles can be gauged, right down to parallel faces, a thing which cannot be done with A and B because of their manner of pivoting.

Bevel-Edged Flats.—Iron and steel bars are made with either one or both edges bevelled, to various angles, and are used for a variety of purposes. In many cases they save the trouble of taking off edges in the forge or machine shop. They are mostly made in small dimensions.

Bevel Gear Blanks.—These are the prepared bodies of wheels, complete in all respects and dimensions except cutting of the actual teeth. They are made of cast iron, steel, brass, gun metal, phosphor bronze, and other alloys, and raw hide. In the smaller sizes they are often sawn from round steel bars, and turned up.

The mild-steel blanks are insisted on in some specifications, taking the place of cast steel, the reason being that the latter are apt to have concealed blow holes which are not apparent until after a good deal of money has been spent in machining. These holes may be closed by electric

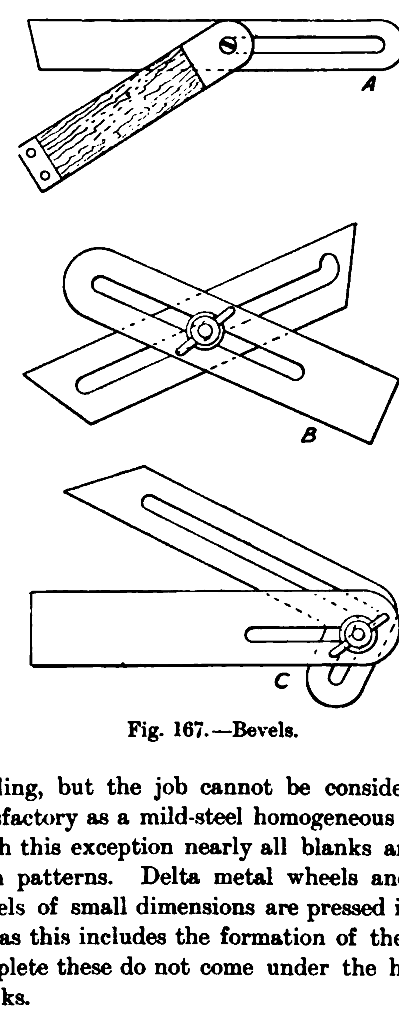


Fig. 167.—Bevels.

welding, but the job cannot be considered so satisfactory as a mild-steel homogeneous blank. With this exception nearly all blanks are cast from patterns. Delta metal wheels and steel wheels of small dimensions are pressed in dies, but as this includes the formation of the teeth complete these do not come under the head of blanks.

It is usual to cast blanks solidly, that is the rim is made thick enough to comprise the actual rim and the lengths of the teeth. The practice is departed from in heavy wheels, say of over about 1¾ inch pitch, teeth being cast or

gashed in these, but with considerable allowances for cutting; the reasons for this distinction, are as follows:—

In the smaller blanks it is much better to cut the teeth from the solid, either in one or in two cuts, a stocking and finishing cut, than to take a light cut on rough-cast faces. The first, paradoxical though it may seem, inflicts much less damage on the cutter than the latter, because the first cuts metal, while the scale, sand, and hard skin on the latter dulls the edges of the cutter rapidly. But in the larger blanks the great difference in the thickness of the metal in the solid rim, and in the plate, or arms sets up cooling stresses which are apt to strain and distort the wheel, or to induce blow holes. It is better then to rough-cast the teeth. This device also will save one cut round, sometimes two. But if a mild-steel blank is used there is no such strain set up, nor risk of the blow holes. But the amount of turning is increased, because the blank is made solidly, and the plated web has to be turned out. At the steel foundries, however, such blanks are roughed out at a small cost.

Bevel gear blanks are drawn out by the principles laid down in the article **Bevel Gears**. But this method is often modified in some details in the case of gears that have to be cut, though for pattern work the methods there described are generally followed absolutely.

In laying out blanks to be machine-cut, the pitch planes are drawn, and then the addendum is added, taken as equal to one diametrical pitch on the major radius. This graphic method is the safest to adopt. But rules are also employed based on trigonometrical relations. These are given fully in "Formulas in Gearing" by the Brown & Sharpe Manufacturing Co., pages 12 and 13.

When blanks have been marked out, templets are made from the drawing, and used for turning them by to ensure diameters and angles being correct. In some shops blanks are milled, using a form cutter which ensures numerous similar blanks being alike.

Bevel Gear Cutting.—This is not nearly so simple a process as it was a few years ago. Then with rare exceptions all teeth were produced by rotary cutters. Within these last dozen years or so, much of this work has been thrust aside by new types of machines, in which tools of the planer type have been substituted for milling cutters, or by the generating machines. These are employed less in cutting the teeth of spurs than of bevel wheels, which have always been produced in a more or less unsatisfactory way with revolving cutters. Their design and growth is a direct result of the increased demand for correctly shaped bevel teeth, which cannot be perfectly produced by such cutters. When a very close approximation to accuracy is insisted on, then this method becomes expensive and troublesome. Hence though machines which produce the teeth by planing have been in existence for over a quarter of a century they have only become rather common during about the last dozen years. These are now constructed in England, the United States, and on the Continent; a few firms make a speciality of these machines in various sizes and types.

The cutting of bevel wheel teeth involves two matters chiefly, one being the selection of suitable cutting tools and the other the settings of the blank. The rotary cutters used for spurs are of no use for bevels of the same pitch, because as they exactly fill the tooth spaces which they produce they are too wide to pass between the small ends of the teeth of bevel wheels. The large ends only of the teeth of bevels correspond with the dimensions of spur wheel teeth of similar pitch. Bevel wheel cutters therefore are thinner than those used for spurs, though numbered similarly. There is a limit to this however, and it is set at a gear the length of teeth in which does not exceed one-third the distance from their outer ends to the points where the centre lines of the shafts meet. This leaves the tooth thickness, and of course the tooth space not less than two-thirds the thickness at the outer end. The cutters are selected for wheels the numbers of teeth of which correspond with the projected diameters measured from the axes to the pitch cones, these lines being at right angles with the pitch cones. So that it always must happen that numbers of teeth for which the cutters are selected exceed the numbers of teeth actually in the wheels. The number

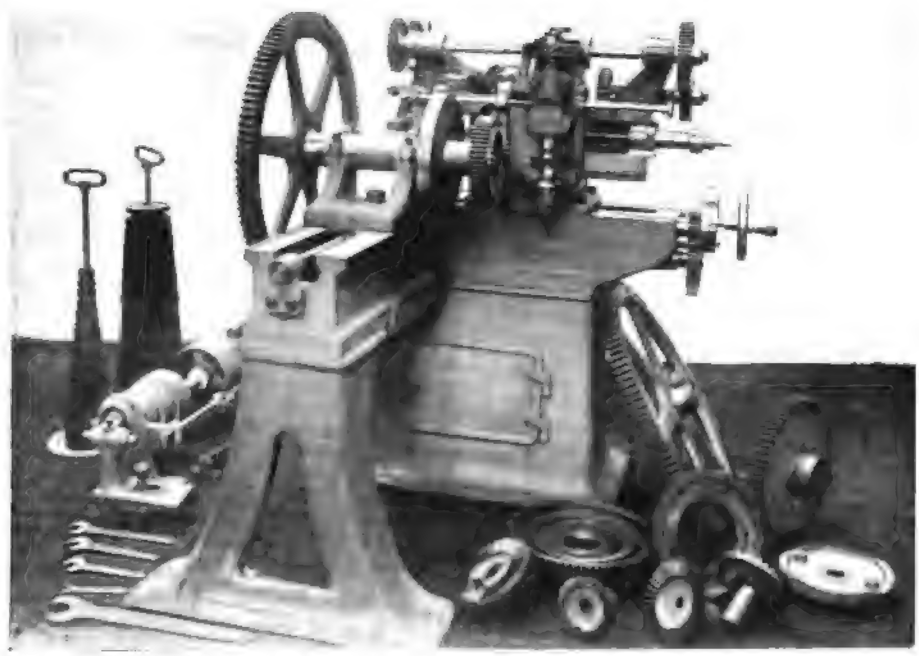


Fig. 168.—Wheel Cutting Machine. (G. Birch & Co.)

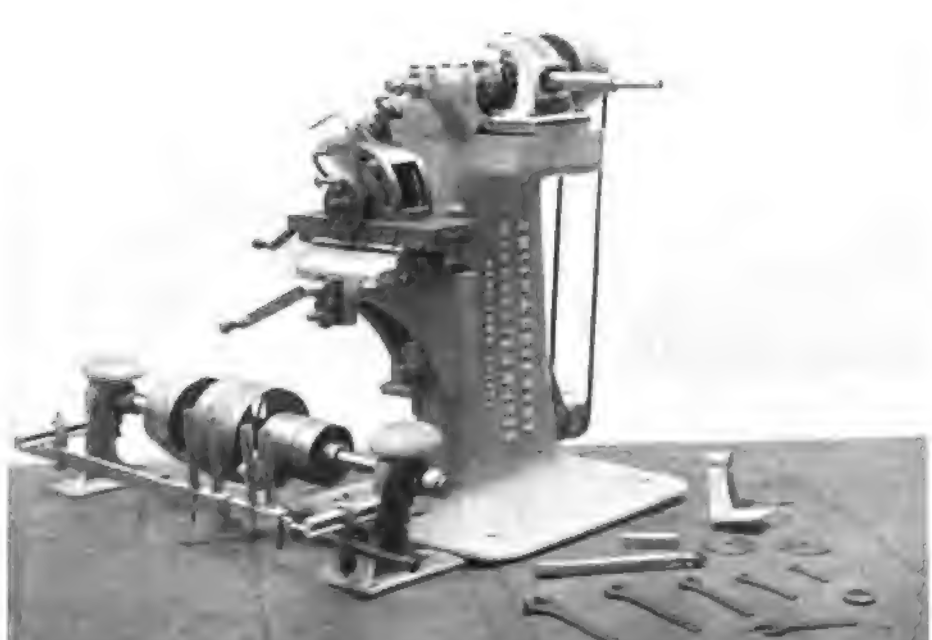


Fig. 169.—Hamilton Machine. (Smith & Coventry, Ltd.)

To face page 166.

will be greater with flatter than with steeper pitch cones. Only in mitres will the same cutters serve for the two wheels in engagement.

But the selection of cutters is not always made strictly on this basis, when pinions with low numbered teeth are in question. It is impossible to shape the flanks of any bevel wheel teeth with absolute accuracy by rotary cutters, because the section of the cutter is constant, and that of the tooth varies continually from one end to the other. Several courses are open. One is to select cutters strictly to correspond with the larger diameters. Then the curves will not be correct elsewhere, until at the small ends of the teeth there will often be a difference equal to that of three or four diametrical pitches. Another is to select cutters for a pitch situated about one-third of the length of the teeth away from the large ends, and so average the difference between the large and small ends of the teeth, neither being then exactly correct. Or two cuts can be taken down each side, instead of one, the second cut on each side being adopted specially to complete the smaller ends of the teeth. Or, what is generally done in wheels of small dimensions, the file is used at and near the small ends, following after the cutting, to reduce the widths of the tooth points towards the small ends.

Generally the first operation in cutting the teeth is to remove the bulk of the metal with a central or "stocking" cut, which goes down to the bottom of the teeth. This operation may be frequently omitted in the smaller gears after the settings of the wheel and cutter have been settled exactly by trial. The first cut when taken is done with the cutter set centrally with the axes of the blank. If the cutter happens to be of exactly the same thickness as the spaces between the teeth at the small end that determines the width of these spaces at once. But when, as more often happens it is thinner, trial has to be made to get the exact width of the space correctly. The wheel blank has to be rolled by rotating the shaft of the dividing worm by hand, and the tooth faces to right and left of a space are cut by trial until the tooth thickness is right at the small ends of the teeth. If now the cutter is shifted laterally, first to right and then to left, just to come in contact with the small ends, and cuts taken right through, the widths of the teeth spaces and the tooth thickness at the large ends should be right. It is in checking these dimensions that the value of gauges comes in more than in cutting spur gears. When all is right the amount of rolling over is noted and also the lateral displacement of the cutter, and one side of all the teeth is then finished and afterwards their other sides.

When these data are once obtained it is not necessary in small gears to take a central cut, but the first cut can be utilised to finish all one side, and the second cut all the other sides.

Though the tooth thicknesses at the small and large ends are thus secured, the tooth cones are not then right at all sections, simply because the cutter produces uniform cones from end to end. What happens is this. The wheel blank is set on its arbor at such an angle that the bottoms of the teeth spaces are cut to the correct angle. If the cutter is of the correct section at the large ends, the teeth cannot be tapered properly at the points, but will spread too much from the pitch line outwards. It is this excess which is filed off tapering down from the small ends to nothing at the large. Or the same result can be secured by rolling the gears after the first cut has been taken and removing more off the upper parts. This is a compromise, since it leaves the large ends rather thin. The steeper the angle of the pinion the more apparent is this result, so that in some cases a cutter having a flatter radius but narrower is substituted.

This is a general statement of the production of the teeth of bevel gears by means of rotary cutters, which is the most common method. For other methods, see **Bevel Gear Generating Machines, Bevel Gear Planers**.

Fig. 168, Plate VIII., illustrates the usual or standard type of wheel-cutting machine for bevels, spurs, and straight-toothed worm wheels. The blank is carried in a dividing headstock which is traversed along its bed to suit the different radii of gears to be cut. The large size of the dividing wheel will be noticed, because it

is essential in order to reduce errors in pitching. The worm, which is hidden behind the bed, can be thrown out of gear to permit of turning the work around by hand when making rough adjustments. On a bed at right angles to that just named, the cutter head is carried on a traversing bracket, and can be swivelled from the vertical and horizontal with suitable graduations for cutting bevels or worms. The head has a vertical slide and screw for adjusting the height of the cutter. The spindle is gear-driven. Change gears are provided for varying the feed, and the self-acting feed motion has automatic throw-out. A set of 33 change wheels is provided for cutting all numbers up to 100, and every even number up to 200 teeth. Samples of the work done on the machine are seen lying around.

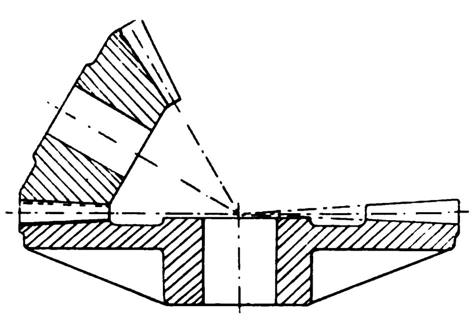


Fig. 170.—Crown Bevel Gear.

Fig. 169, Plate VIII., is a machine designed for cutting bevel gears specially, and one which has long been established in favour in the shops. The feature of the machine is, that although a rotary cutter is used, its spindle has a reciprocating movement as well, which by means of an eccentric decreases in amount as it approaches a certain point, so that it cuts the tapered form of tooth by virtue of this reciprocation.

The headstock is carried on the top of a hollow casting. It has self-acting traverse and automatic stop motion, so that the machine is brought to a stand at the termination of each cut, remaining thus until started on a fresh tooth. The work table is carried on a knee with longitudinal and transverse slides, the former having an index by means of which the axis of the work can be set exactly under the centre of the cutter. The table has a universal head with hollow spindle; it can be set to any angle. Dividing is through worm and worm wheel.

Bevel Gear Generating Machines.—In these machines there is no former used, as in the planer type, nor rotary cutters having sectional shapes the reverse of those of the teeth, but the mechanism of generation is embodied in the design of the machine. Few of these have been made, but their numbers may be expected to increase. There are five or six successful types, the Bilgram, the Robey-Smith, the Warren, the Monneret, and the Beale, and each differs in important elements of design from the others. A brief notice of the principles embodied in each follow :—

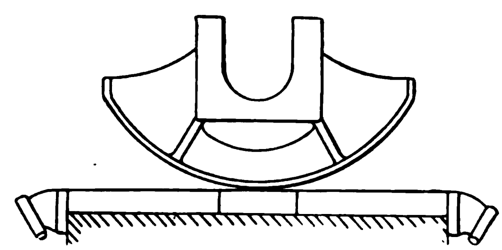


Fig. 172.—Evolver or Roll Cone of Bilgram Machine.

In general, the essential principle which lies at the basis of all machines of this type may be stated thus. The generating tool, or tooth represents in spur gears a rack tooth having straight flanks set at an angle, and the machines are so designed that this cuts all teeth of all wheels of the same pitch, as though the blank were a plastic body being rolled in the same relation to the cutter as the gears would take relatively to a rack. But as in strictness rack teeth do not exist in bevels, the real basis is an absolute crown bevel wheel, Fig. 170, or one in which the pitch planes do not form a cone, but an absolutely horizontal plane, and the tooth

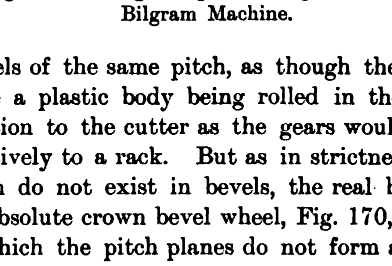
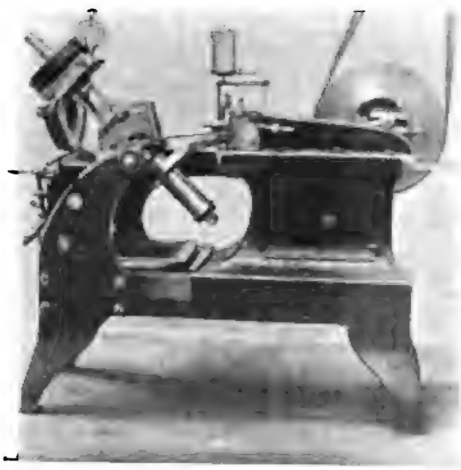
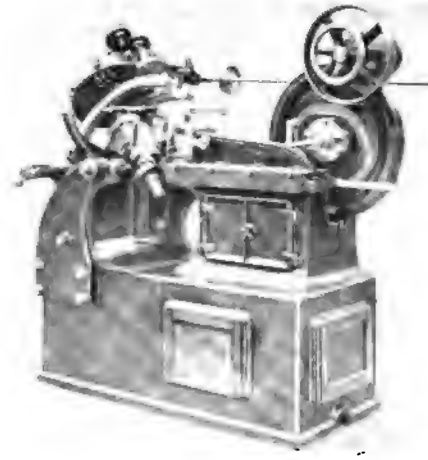


Fig. 173.—Wedge-Shaped Cutting Tool used in Bilgram Machine.



Ordinary type.



Fully automatic.

Fig. 171.—Bilgram Generating Machines. (J. E. Reinecker.)

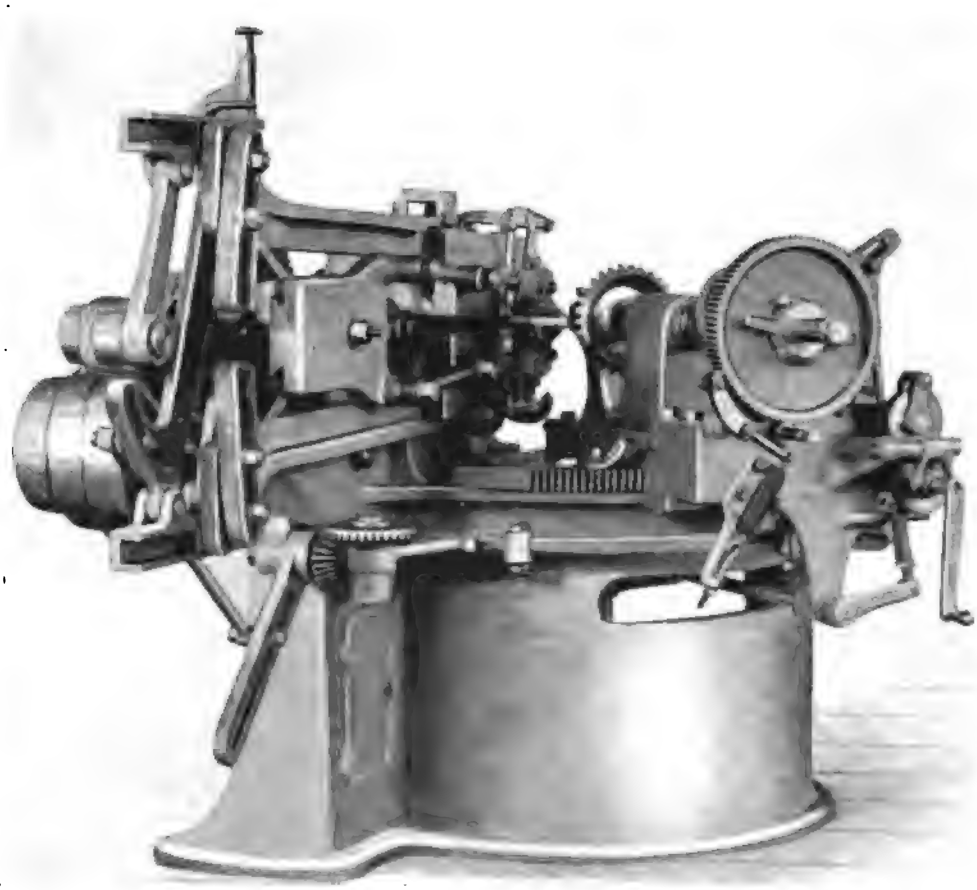
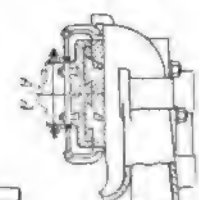


Fig. 174.—Robey-Smith Generating Machine. (Smith & Coventry, Ltd.)

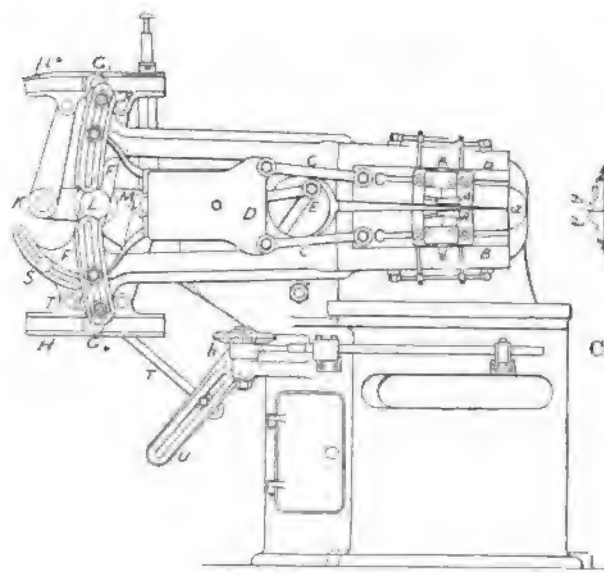
To face page 168.

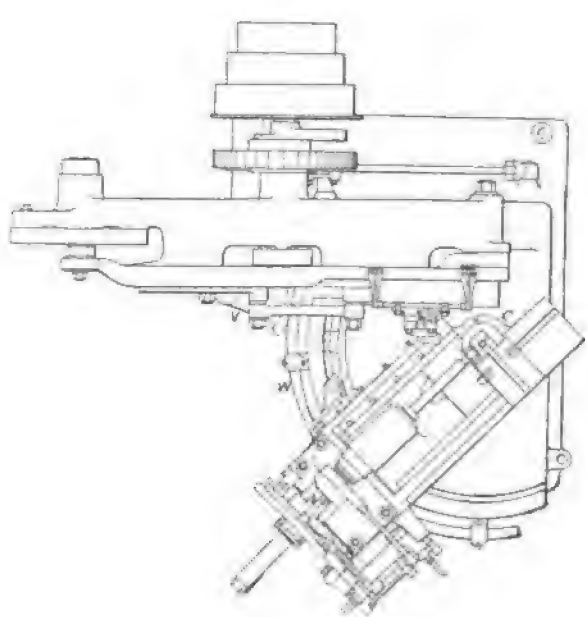
form produced has been termed an octoid. Such a gear is practicable, and it is convenient and correct to assume it as the basis for generation. But beyond this, details go widely apart.

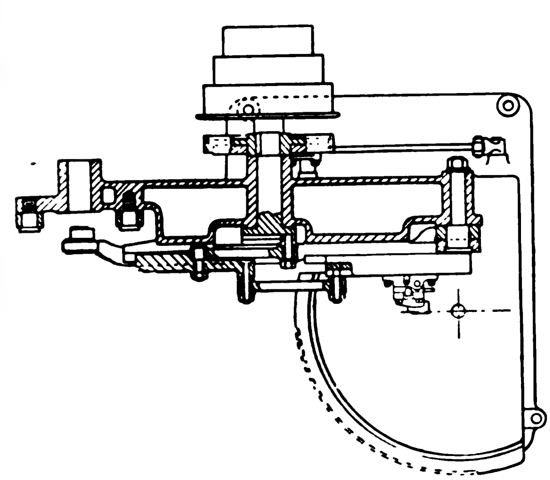
It should be mentioned that generating machines will only produce single curve, or involute teeth. If double curve, or cycloidal teeth are required they must be planed on a former machine, or produced by rotary cutters. In the Bilgram machine, Figs. 171, Plate IX., the generating mechanism takes the form of an evolver, Fig. 172, distinct from the mechanism of the cutting tool, the shape of which is that of a broad shaving tool of vee section, Fig. 173. The tool reciprocates only after adjustments have been effected, so that the tooth shapes are imparted by the movement of the blank, which is compounded of an oscillation in a vertical plane, and a rolling on the pitch surface. The cutting of wheels of different bevels is provided for by the arbor, see Figs. 171, Plate IX., which has both angular adjustment, and oscillatory movements. The first is effected in a vertical plane between two quadrant uprights, exact setting being ensured by a vernier moving over the graduated edge of a quadrant, which permits of setting to minutes of arc. Clamping is done by means of nuts. The second movement is effected by a motion of the arbor, &c., round a vertical axis, through the medium of a hori-



Cross-Section of Slides.







Plan of Base of Machine.

Fig. 175.—Robey-Smith Machine.

zontal plate which carries the quadrant pieces and the arbor, and a movement of the "roll cone," Fig. 172. The latter completes the rolling movement imparted to the blank, and is the fundamental idea embodied in the machine. It coerces the movement of the upper end of the arbor, and so imparts a rolling motion to the wheel blank. For each bevel wheel there is a separate cone,—exact, or approximate, twenty-two being supplied. Each forms a portion of a conic frustum corresponding with the cone angle of a bevel wheel, and each has its angle marked upon it. The cones are coerced by steel bands attached to roll boxes on opposite sides of the machine, seen in Plate IX., and in Fig. 172. The machine is set by a pointer, and zero line for right and left hand cutting on opposite sides of the teeth. Dividing apparatus is fitted, being either index plates or change gears as desired. All the flanks on one side are cut, and then all those on the other.

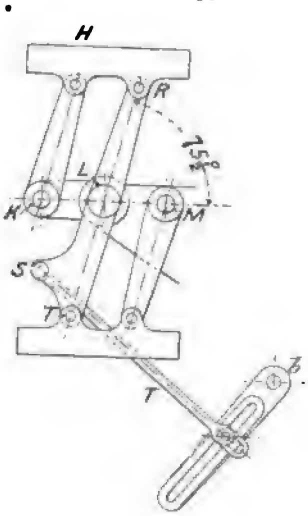


Fig. 176.—Diagram of Link Motion.

There are many details relating to feeds, and operations, which we cannot give space to describe, contenting ourselves with the essential elements, and leaving the photos to explain themselves.

The Robey-Smith bevel gear-generator-planer, Fig. 174, Plate IX., has two tool arms adjustable for angle, and these operate simultaneously on opposite sides of a tooth, and lift also on the return stroke. Necessarily the angle varies constantly between each cut. Hence the mechanism is so arranged that after each cutting stroke the blank is revolved through a distance equal to the pitch, so that at any given angle each tooth receives a single cut on each flank, after which the angle is changed automatically. The generating mechanism employed comprises a series of links as follows:—

In Fig. 175, showing the machine in elevation and plan, the cutting tools are seen at A, A carried in their tool boxes, and having their reciprocating arms coerced by the slide B, the details of which are shown in the cross-section. The slides are hinged at the centre *a*, hence the tool always moves radially towards that centre. The tool boxes receive their motion from the connecting rods C, C pivoted on the crosshead D, and actuated by the adjustable crank E. The slides B, B are extended, and terminate in quadrants F, F. To these are bolted two pieces which terminate in pins G G entering blocks fitted into two slides H H. These last are connected by a series of links which form a parallel motion, as shown separately by Fig. 176. The three points, K, L, M are fixed on the centre line of the machine, and if therefore the lever R, L, T is moved, the two slides H H must move also, approaching to or receding from the centre line by the same amount, and parallel. As their distance apart increases, they open the slides B B, thus increasing the distance between the cutting edges of the tools. The mechanism by which this is accomplished automatically is as follows:

An extension of the lever R, L, T receives a pin S terminating a connecting rod T. The farther end of T can be locked in a slotted link U, which swings round a centre *b*, and the link is keyed to one of a pair of bevel wheels, one of which actuates the quadrant V. The teeth of the latter engage with teeth cut on a quadrant bar W, and the latter is locked to the carriage which receives the arbor and blank, and the dividing head.

The carriage pivots round the centre *c*, and is actuated by a worm, engaging in a curved rack. It follows that the motion of the carriage imparts a rocking motion to the lever R, L, T pushing the slides H H apart and increasing the distance between the edges of the tools. The blank thus moves laterally towards the tools simultaneously with the widening of the distance between them. The object of the slotted arm U, is to permit of sliding the connecting rod T to different positions, to suit differences in length of radius of involute tooth curves.

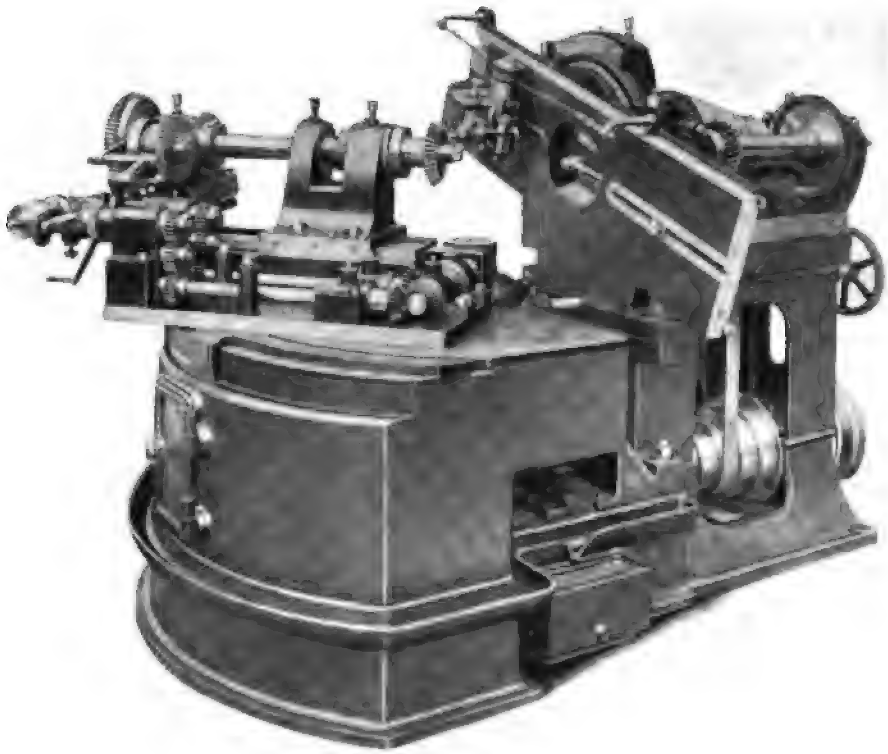


Fig. 177.—Monneret Bevel Gear Generator.

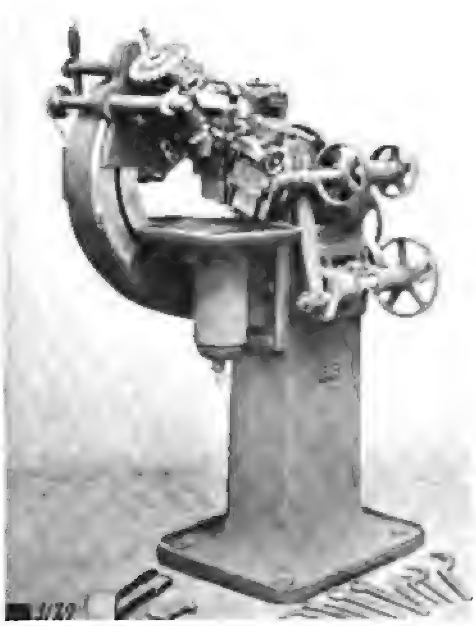


Fig. 179.—Warren Machine. (Ludwig Loewe & Co.)

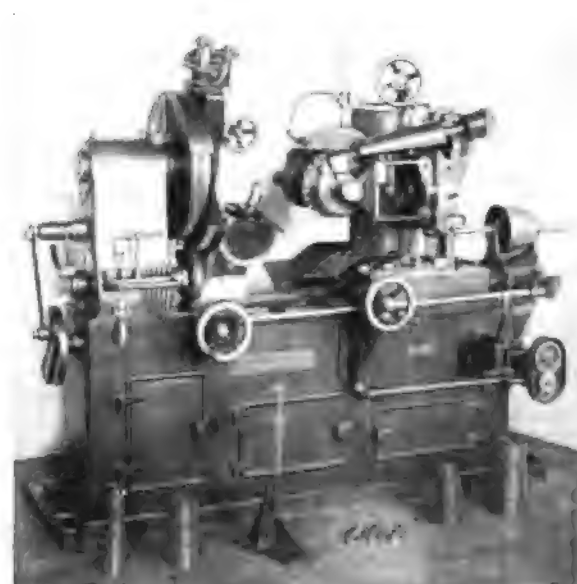


Fig. 180.—Beale Machine. (Brown & Sharpe Manufacturing Co.)

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In Fig. 175 a plan of the machine framing in section, is shown with the carriage removed.

The machine of M. Monneret, Fig. 177, Plate X., and Fig. 178, made by H. Ernault, of Paris, is unique in its method of operation, inasmuch as it pitches without a division plate, and also cuts a tooth slightly helicoidal in form. The blank is being constantly rotated, so that only one cut is taken on each tooth at a time, the next being taken on the tooth adjacent, and so on. The helicoidal form is produced by imparting a slow intermittent rolling feed independently of the main movement of rotation, which is continuous. The A, and the apex of the pitch cone. B is the arbor, and C a quadrant rack, with graduations into degrees, and driven by bevel wheels and a crank, so that one turn of the crank equals one degree, and fractional parts are obtained by other graduations. The headstock cones D, back geared, both actuate the arbor and blank, and tool holder. The first named is effected through change gears E, through a vertical shaft the axis of which lies in that of the pivot *a*. Hence the motion of the tool slide and that of the wheel blank synchronise by reason of their connection through gears. Detail drawings would be necessary to trace out these connec-

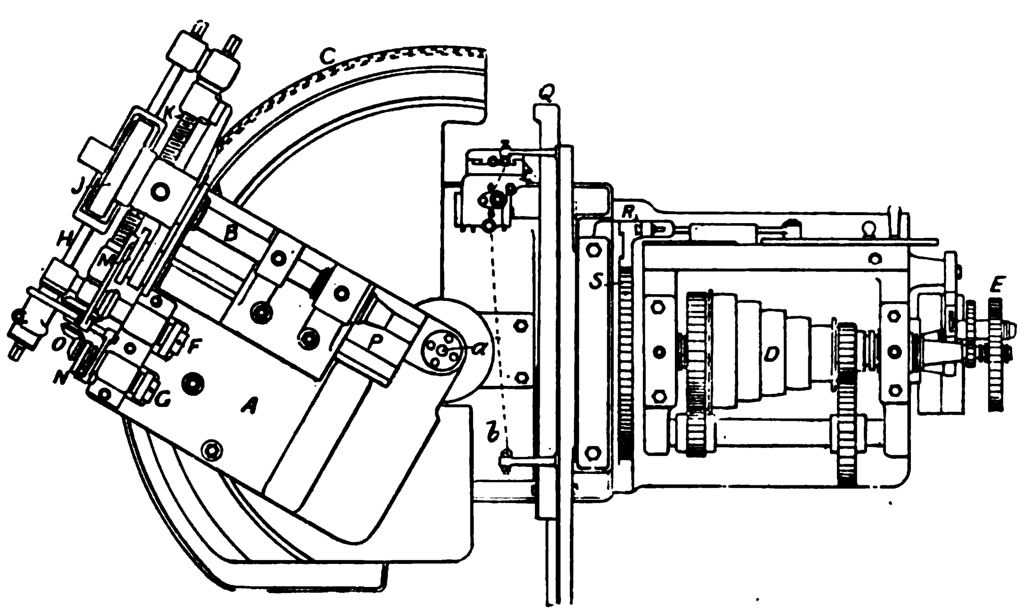

Fig. 178.—Plan of Monneret Machine.

movements are wholly automatic during the cutting of one of the sides of all the teeth. The section of the cutting tool is that of the tooth of a crown wheel, and of a semicircular shape when looked at from the face. The blank is carried with its arbor horizontally on a carriage which moves round a pivot, with its axis vertical, and is carried on a horizontal bed, on which it is clamped to impart the sectional angle. But the lateral or flank angles are produced by the movements of the headstock, which impart feed to a tool slide seen in front of the headstock.

In Fig. 178 *a* is the pivot of the carriage tions, for which our space is insufficient. But they are briefly as follows:—

The change gears E rotate a shaft that passes horizontally below the headstock, driving through bevel gears the vertical spindle concentric with the central pivot *a*. Thence bevel gears actuate a short horizontal sleeve enclosing a spindle with two sets of wheels, one of which drives a horizontal shaft in the same vertical plane as the gear F. Another spindle parallel with this, and beneath gear G, is driven from the other in a rather roundabout fashion. The motion of the spindle beneath F is communicated to the worm shaft H, which in turn operates the blank

arbor B, through worm gear J. This worm gear is made to fulfil the double function of rotating the blank, and imparting the feed. The worm slides in a key groove in its shaft H, being confined in a box fitted to the screw K. It is therefore fed lengthwise by the rotation of the screw, so fulfilling the function of a rack to the worm wheel as well as its own proper work of rotating the wheel. This feed movement is transmitted from the arbor B, that carries the blank and the worm wheel J, through equal spur wheels to a slotted crank disc M, that in turn actuates a ratchet wheel N with a pawl acting either way. Thence the feed movement is transmitted through the mitre wheels O, to the screw K, which imparts the longitudinal movement to the worm. Thus the helicoidal cutting is done, and the pitching of the teeth.

As already remarked the movement of the tool slide on the front of the headstock synchronises with that of the blank. A slotted disc crank at the front of the headstock spindle, and having an adjustable block and screw, drives the tool box through a connecting rod, and it has also a swivelling movement.

On the spindle of the ratchet wheel N, there is a gear G, which transmits motion through a train of spur wheels to the spindle already mentioned, as lying beneath it, thence through mitre gears to a spindle passing down through the centre of the pivot *a*. This rotates a horizontal screw working in a pivoted nut below the carriage C, so that whatever the angular position of the latter the screw is parallel with the feed screw K, and this operates the slide P, at a rate that is governed by the angle at which the screw lies, and which in turn is produced automatically by the setting of the carriage. The slide P has a rack on its lower face which imparts motion through a train of spur gears to the tool plate Q through a vertical rack R, engaging with a wheel S, at the rear of the plate. In this way the oscillatory feed is imparted to the tool slide, being one of intermittent rotation about its own axis, and taking place at the termination of each revolution of the blank, which corresponds with a single cut taken off each tooth. A cord *b*, lifts the tool on the return stroke.

We now come to a small group of generating machines in which rotary cutters are employed. But the same principle underlies their action as that of the reciprocating or planer cutters. That is, they represent the crown or rack tool, and the rolling of the blank past them produces the single curve teeth correctly in all sizes of wheels of the same pitch. There are two good machines in this group, the Warren and the Beale. They each have individualities which render them unique.

The Warren machine, Fig. 179, Plate X., is a result of the endeavour to produce bevel wheels for chainless cycles. It employs rotary cutters, the cutting face of each of which is identical in angle with the crown gear tooth already noted. Two cutters are used to operate on the opposite sides of adjacent teeth, or those which face each other. They act with reciprocating strokes, while the gear blank and the cutters are rolled past each other. They are rotated in slides which are fed along at the required bevel. A loose connection is required to permit of the double motion, and this is effected through telescopic shafts with gimbal joints, driving equal gears on the spindles. The cutters are fed along the teeth by slides, and rotated at the same time, while the gear blank is oscillated through a distance equal to the length of the arc of contact of the teeth.

A recent generator, the Beale, Fig. 180, Plate X., embodies rotary cutters producing opposed faces of adjacent teeth simultaneously. A roughing cut is taken in the forward motion of the gear, and a finishing cut on its return, the tooth spaces being roughed out previously. The cutters are carried in slides with angular adjustments, telescopic shafts, and gimbal joints.

The cutters represent the tooth of a crown gear, and the teeth are staggered and interlocked in order to act simultaneously. The inclination of the cutter arbors can be altered to suit gears of different obliquities. Their axes are inclined slightly in a position perpendicular to the tooth angle, in order to impart the flank bevel to the teeth, and this angle is adjustable to suit wheels of different cone angles. They can also be adjusted lengthwise to suit different pitches, though this is rather limited due to the interlocking of the teeth, the operation of which

would be interfered with by too much closing up, or separation. The cutters are not fed through the tooth space, hence they are large, in order to avoid a pronounced concavity.

This is the principle of the device. The details can only be briefly noted.

Looking at the photo, Fig. 180, Plate X., a

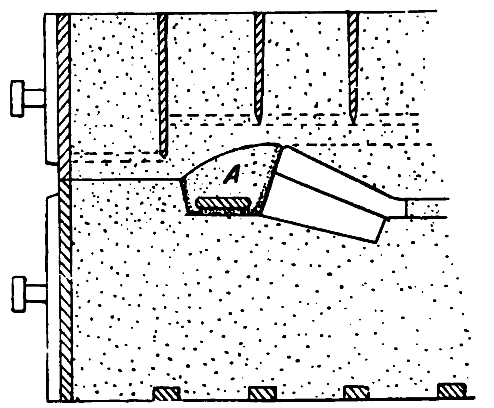

Fig. 181.—Crown Wheel requiring Loose Ring of Sand.

large index worm wheel is seen to the left, on the spindle of the headstock, and it carries on its face a bevel gear that produces the rolling motion imparted to the blank, and which is actuated from a connecting rod seen at the rear end. This rocks a sector gear, and thence a pinion engaging with a segmental gear on the face plate. A bevel pinion above engaging with the bevel teeth on the index wheel is thus rocked on its stationary bevel gear during the intervals of indexing; and through change wheels seen above, and a vertical shaft and gears, it rocks the spindle which receives the blank arbor. This spindle can be adjusted by graduations to suit the cone angle of any gear, and the change gears are proportioned to suit different wheels that require different rolling motions. As changing these gears would affect the indexing, a set of compensating gears is introduced on the opposite side of the machine in reverse order to those put in above. To permit of adjustments of the cutters to suit different pressure angles of teeth, their arbor supports are carried on circular guides with graduations on the circular arcs. Other circular guides permit of adjustments for the sides of the teeth. There are other movements for width of tooth space, and for up-and-down motions of the cutter head. There are other details, but these suffice to render clear the principle of the operations of the machine.

There is another machine, the Grant, which generates teeth with a circular cutter. But it is not an involute tooth, since the tooth flanks are straight, and the tooth faces are epicycloids.

Bevel Gear Moulding.—This relates to the moulding of gears from complete patterns. The general method is illustrated in the accompanying figures.

A wheel is shown first, Fig. 181, with a very flat bevel, of that type termed a crown wheel. Hence the bevel of the teeth ends is so slight that the sand would not lift therefrom on the outside readily without risk of becoming broken down, hence the reason why the loose ring A is introduced. In the other example, Fig. 182, there would be no need to use the loose ring, but the joint would be at the edges of the teeth, and the lifts for top and bottom be vertical.

Another point is that when making bevel wheels it is much better to leave vertical arms, when present, loose with dowels instead of fast, for convenience of lifting in the top. Being loose the sand is not torn away from them, but they come up along with the sand and are withdrawn after the cope is turned over.

To mould the examples given, the wheel is

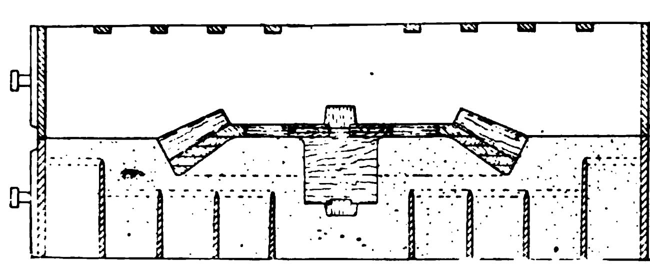

Fig. 182.—Bevel Wheel in position for Ramming Bottom Face.

first placed on the top box, or cope, Fig. 182, laid upon the ground, and filled loosely with sand. The ring, in the case of Fig. 181, is bedded also around the wheel. The joint face is smoothed level with that, and with the faces of the flat arms. Parting sand is strewn over, the bottom box, or drag put on and

rammed, good strong facing sand being put over the teeth. No sprigging is necessary as in spur wheels. The drag is vented down

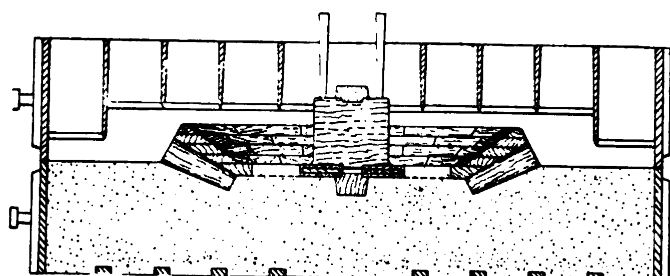

Fig. 183.—Bevel Wheel with Top Box, in position for ramming.

to the pattern face, parting sand strewn over its back, the flasks turned over together and laid on a level bed.

The top is next lifted and knocked out, the joint face rubbed over with the hand and smoothed, more parting strewn over, the ring A, in the case of Fig. 181, laid back in place, and sand laid on and pressed down and flat rammed, rounded off with the hand; parting sand is then strewn over that and over the entire joint faces beside, the loose arms, if present, put in, and the top box laid over, Fig. 183, liftered, rammed, and vented from the top. When lifted, it is turned over on blocking, to allow of the withdrawal of its arms if these are left loose.

Before the wheel can be drawn, in Fig. 181, the ring of sand A has to be lifted away. Being so shallow there are of course no eyes in it, so three or four gullets are cut down through the sand surrounding it, and a hook or the fingers inserted by which it is lifted away bodily. The pattern is then drawn, the ring returned into place, and all cleaned and blacked together. Finally the top is lowered. The metal is run through the boss, see the runner sticks in Fig. 183, where it is also fed.

When a wheel is made with shrouds or friction collars, it is evident that the sand must be taken away as a separate ring under the shroud, which is removed and dried. This can be made in two ways, either as a continuous entire ring of sand, stiffened with a wire bent round in the form of a circle, or it may be made without wires at all, the ring being divided into six or more short segments parted through with the trowel after ramming, and just prior to withdrawal for drying.

Bevel Gear Planers or **Shapers**.—These machines have the advantage over the ordinary rotary cutting machines in producing teeth of more accurate shape than those in which rotary cutters are employed.

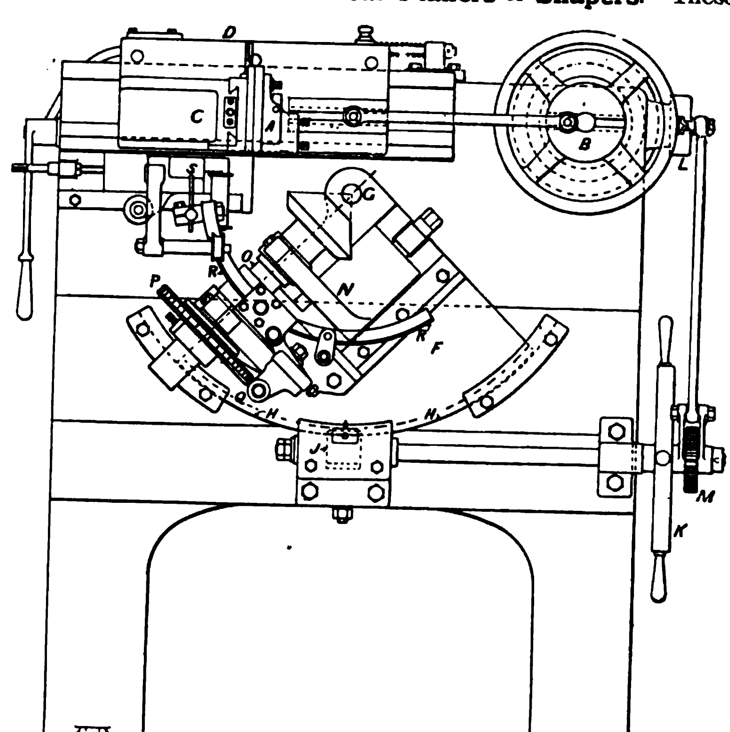

Fig. 185.—Front Elevation of Bevel Gear Planer.

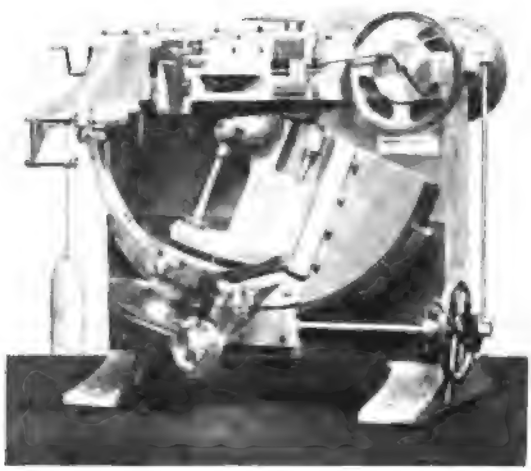

Fig. 184.—Bevel Gear Planer.
(Greenwood & Batley, Ltd.)

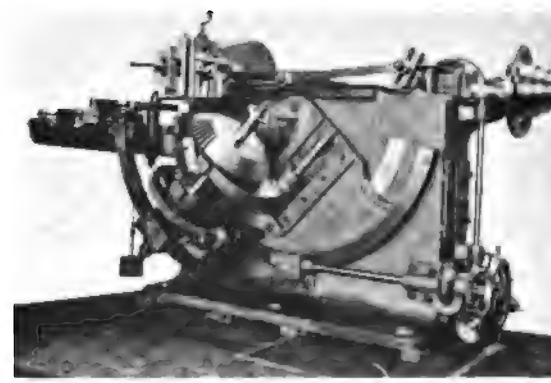

Fig. 187.—Bevel Gear Planer, with Attachment for Cutting Helical Teeth.
(Usines Bouhey, Paris.)

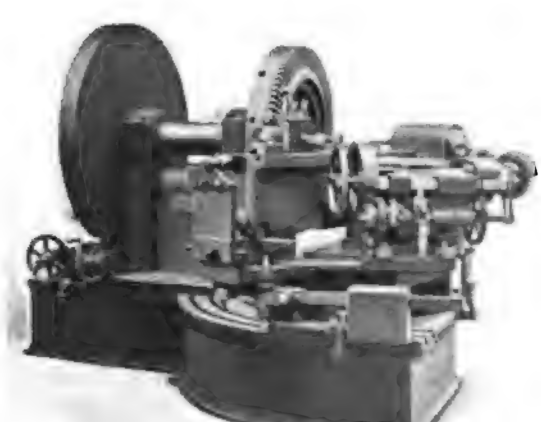

Fig. 188.—Bevel Gear Planer. (Gleason Works.)

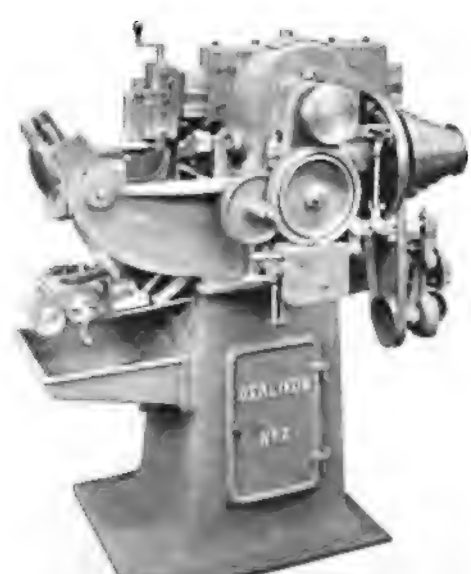

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Fig. 195.—Oerlikon Automatic Gear Planer.

A bevel gear planer must be of one of two types; either that in which a former, or master tooth is employed, or one which generates the correct tooth shapes without any assistance from a former. Generally the term is understood as applying to the first named, notwithstanding that most generating machines employ the planer class of cutter.

In a machine of the planer, and non-generator type, the action of the tool, however produced, is controlled by a tooth curve or curves cut on the edge of a former, but made three times, or more, larger than those of the teeth being cut, the object of enlarging being to lessen risk of error. Clearly then the degree of correctness of the tooth shapes depends on that present in the former, and afterwards on the accuracy of the machine fittings. It is easy to see that slight errors in these may be cumulative, and so result in the production of gears no more accurate than those shaped with rotary cutters. And this has in fact sometimes been the case, and hence a strong argument exists in favour of the generating machines. An objection to weak gear planers is the spring of the arms. Neither do those machines score over the rotary cutters on the point of economical production in the case of the smaller gears.

Substantially the essential mechanism of a machine of this kind comprises an arm carrying a reciprocating tool which is capable of a strictly linear motion only. The wheel must always move relatively to this tool in such a manner that the cutting shall take place towards the apex of the pitch cone. The wheel blank must therefore partake of two motions, one corresponding with the bevel of the teeth in a direction perpendicular to the wheel axis, the other with their bevel in a lateral direction, or at right angles with the perpendicular. Herein exists much variation in the details of different machines.

A bevel gear planer which with variations is made in England and on the Continent is shown in Fig. 184, Plate XI., and Figs. 185 and 186, adjacent. The one illustrated is by Greenwood & Batley, Ltd. The cutting tool is held in the box A, reciprocated by the slotted disc crank B, and carried on the bracket C, the foot D of which slides on a face and vee'd edge on the machine framing. The sliding face is of very large area to ensure rigidity in operation. Provision is made for varying the distance of the box out from the framing to suit wheels of different diameters, by means of a screw and slide.

The wheel blank is carried primarily by the quadrant plate F, pivoted on the face of the framing at the centre G, which centre corresponds with the apex of the pitch cones of the wheel to be cut. As the cutting tool always travels in line with this centre, the blank is swung thereon to a predetermined amount of feed between each cut. This is imparted by means of a segmental rack H, cut on the outer edge of the quadrant plate, in which gears a worm J, on a horizontal shaft. Rapid adjustments are effected by the hand wheel K, but the feed is imparted by the slotted disc L, and ratchet M, with its pawls.

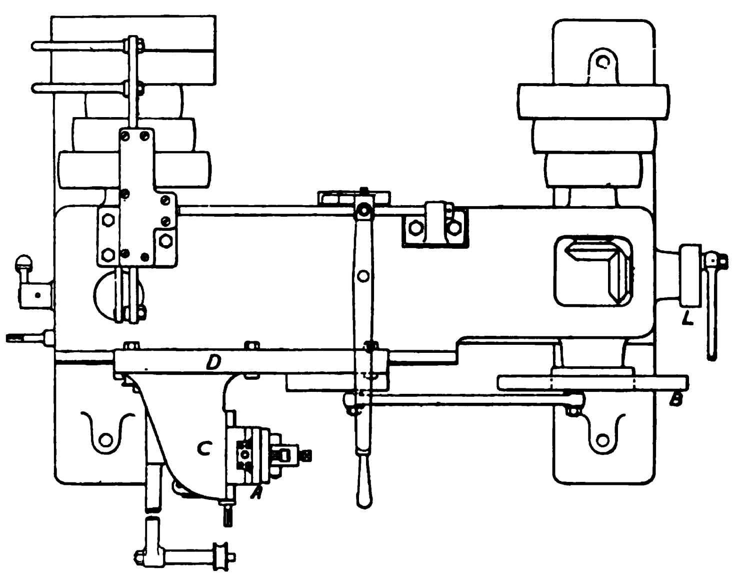


Fig. 186.—Plan of Bevel Gear Planer.

A headstock N (seen only in the front view), Fig. 185, carries the wheel blank. It slides in

vee'd ways in the quadrant plate F, and carries a spindle O, through which passes the arbor to which the blank is attached. A dividing worm P is carried at the lower end of the spindle O, while the spindle of the worm Q carries a dividing plate (not shown) by which the pitching of the teeth is effected.

The mechanism connected to the former comprises, first, a quadrant rack R, to which the former S is attached. The rack rocks upon the

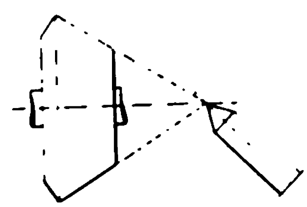


Fig. 189.—Adjustment of Blank in relation to Machine Centre.

hollow spindle O. A steel guide plate moves this in unison with the pressure exerted by the former as it ascends. The two are maintained in contact with suspended weights and this imparts a slight lateral movement to the wheel blank between each cut, producing a profile which is an exact reduced counterpart of that of the former.

When the bottom of a tooth is reached, the attendant turns the quadrant back to its original position, rotates the blank for pitch distance by the division plate, when the cutting of the next tooth begins. The striking gear and some other details are too apparent to call for description. Fig. 187, Plate XI., is a machine resembling this in type, but having mechanism for planing helical teeth.

A machine of a very different construction is the Gleason bevel gear planer, Fig. 188, Plate XI., having few points in common beyond the essential embodiment of a former. Its action is, in addition, automatic in pitching the teeth.

The machine, in regard to its general build, may be termed horizontal, as opposed to the one just described in which the quadrant slides on a vertical face. In the Gleason it slides on a horizontal face, the main base or framing being a bed instead of a standard. Concisely, its essential features may be described as follows:—

The gear blank is mounted on the face plate and arbor of a headstock, which is slid along the bed, and adjusted in relation to a fixed vertical centre on the machine, Fig. 189, which is the apex of the pitch cone of all gears to be cut. The tool holder is carried on a slide, which swivels round this centre to suit the angle of any gear, from mitres, to pairs of high ratios. It is adjusted by means of a scale of degrees cut on the quadrant edge of the machine base, and a pointer. Pitching is effected by a large dividing worm wheel, and change gears, situated at the rear of the headstock. When the headstock is set to the correct pitch cone, and the tool slide set for angle, the machine is put in motion, first by a three-stepped cone pulley, taking charge of cutting, and return strokes, and feeds; and second by a belt pulley actuating automatically the dividing mechanism. The feed is imparted through a worm gear between the cutting strokes of the tool slide, and is capable of variation; and reversal is through adjustable stops operating clutches, and at a quicker rate than the cutting stroke. The slide is able to follow the former, by being hinged vertically on the centre of the pivot which forms the apex of the pitch cone, and its mass is relieved by a balance weight. Three formers are used, one for blocking out; the

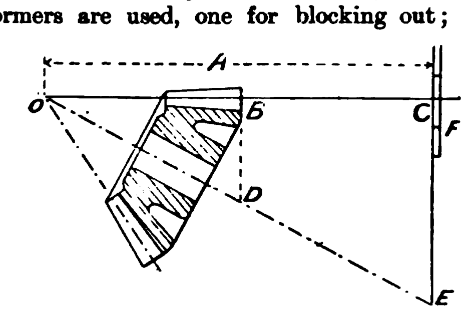


Fig. 190.—Relations of Former and Wheel.

other two, right, and left-handed for the top and bottom sides of the teeth.

The relations of the curve, and proportion of a former F and the tooth of its wheel are shown in Fig. 190. The distance C E is as many times the length B D as the distance O C is greater than O B. As B D is the developed pitch circle of the wheel, so is C E that of the former on which the curves of the latter are struck, Fig. 191, as those of the wheel are struck on B D, A in Fig. 191 being the pitch line for the formers.

The formers used are either sliding, Fig. 191, or rolling, Fig. 192, the latter being far preferable, as less subject to wear than the first named. The method of producing roller forms is shown in Fig. 192, where the circle arcs correspond with the diameter of the roller used. Fig. 193 shows the roller stud at G, and the knife-edge rider at H.

A few bevel gear planers have two tool arms, so operating on both sides of a tooth at one

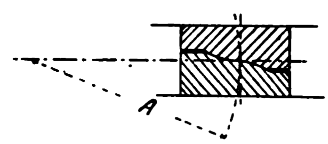


Fig. 191.—Curves of Formers.

time. One of this type by the Oerlikon Works is shown in Fig. 194.

The tool boxes A A attached to the arms B reciprocate towards with the apex of the gear at *a*, while the lateral movement is controlled by the formers at C, over which knife edges slide, contact being ensured by suspended weights (not shown) the cords of which pass over the pulleys *b b*.

The base of the machine is shaped to produce two quadrant slides D D, flanking a central quadrant rack E. A saddle F slides on this,

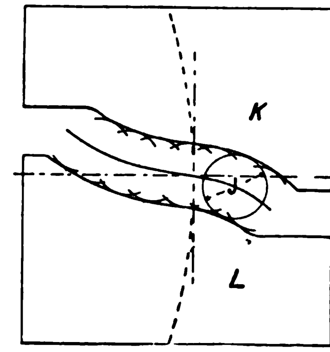


Fig. 192.—Rolling Formers.

and is adjusted by a ratchet handle and gears G, to suit wheels of different diameters and bevels. One end of the blank arbor is carried

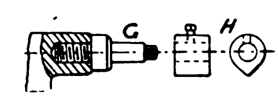


Fig. 193.—Roller Stud, and Rider.

in this, the other in a crossbar H, which both pivots, and is adjustable in bearings J J in the uprights K K, springing from the base of the

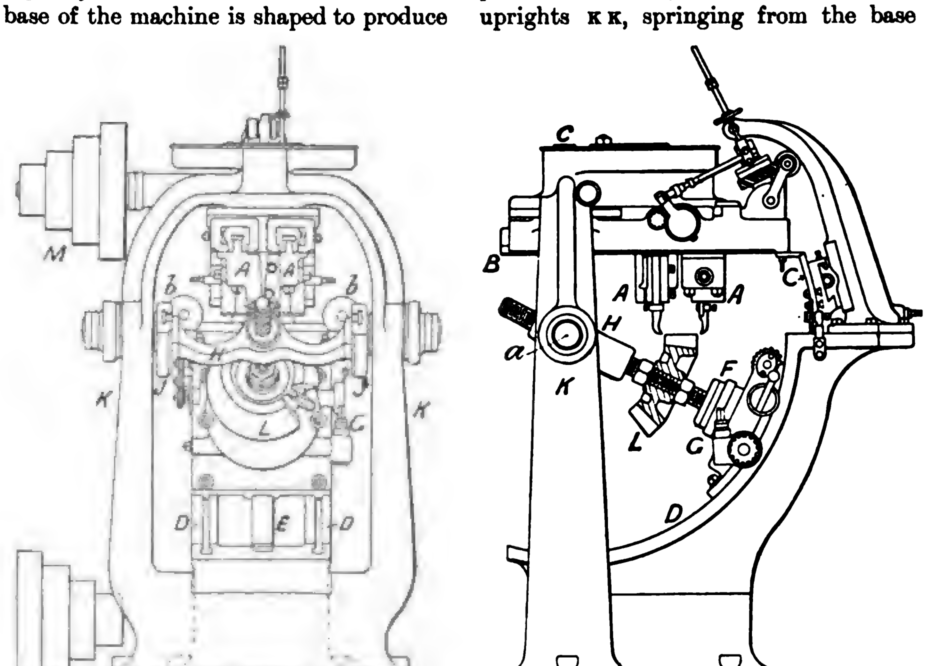


Fig. 194.—Oerlikon Planer.

machine. The wheel blank L is adjusted by means of F, and H, and the nuts, in relation to the apex *a*. The driving mechanism is actuated from the cone M through a worm and worm wheel, a crank disc, a double pinion, and a toothed sector (mostly concealed). The double pinion actuates the racks on the rams B, one of which operates the feed mechanism. The racks and tool holders move in opposite directions, one cutting, the other returning, so shaping the opposite sides of the same tooth, and the pivoting of the head at *c* allows the control of the formers to come into play. When a tooth is finished, the gear is set for pitch by hand, through change wheels, and the tools are set for a repetition of their operations. Fig. 195, Plate XI., shows a later machine using a single arm only, and having automatic arrangements.

The Rice is a former machine. The teeth are produced with a rotary cutter, but the latter is controlled by the teeth of an enlarged master wheel about five times larger, which is generated on a Bilgram machine. Control is exercised by means of a guide plate held in contact with one side of the teeth in succession by means of a weighted lever. The wheel that is being cut is on the same spindle as the master wheel. The rotary cutter does not traverse, and therefore the bottom of the teeth are slightly concave, but as the cutter is of large diameter this concavity is but slight in amount. The arbor of the blank and master wheel swings with a double motion, one about its own axis, the other in a vertical one. It is also carried along to a definite distance by a sprocket chain and wheel. At the same time the guide plate is held in contact with one side of the tooth of the master wheel. The blank partaking of this rolling motion against the cutter receives the involute shape in reduced dimensions. The whole of one side of the wheel teeth are done automatically, after which the cutter is set over for the opposite sides. The tooth spaces have to be roughed out before the blank is put into the machine. The reason why a full master wheel can be generated economically is that the machine was devised for cutting the bevel wheels of chainless cycles in quantity, though it is suitable for any repetitive work.

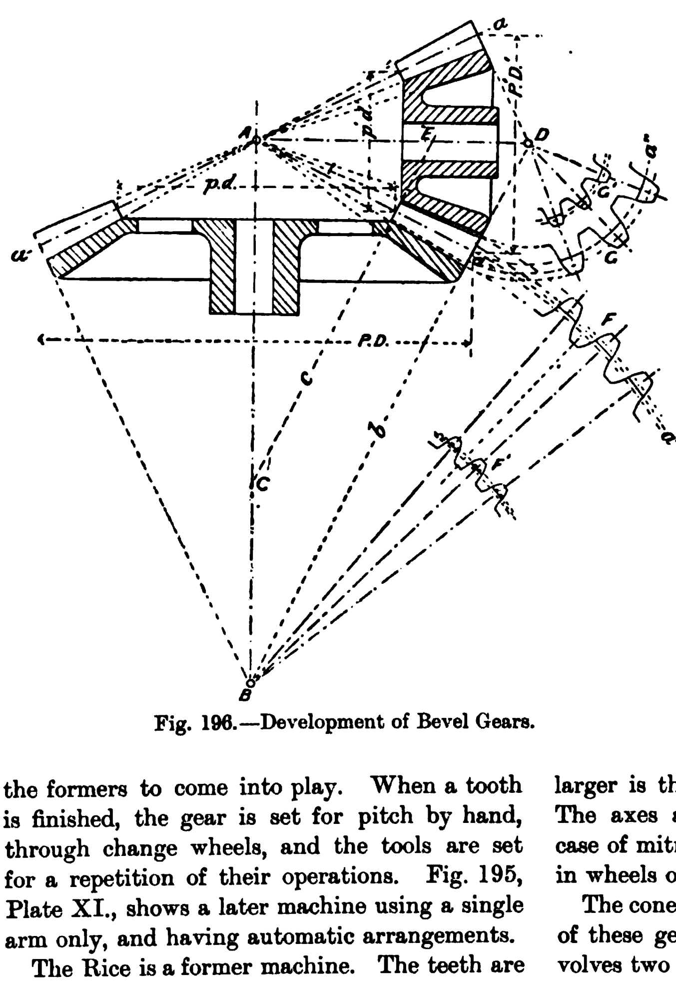


Fig. 196.—Development of Bevel Gears.

Bevel Gears.—These may be described concisely as wheels the pitch planes of which form portions of cones that would if completed meet in the centre of the axes of the engaging wheels. They may be of equal diameter (mitres) or unequal, in which case the larger is the wheel, and the smaller the pinion. The axes are situated at right angles in the case of mitres, but at right, or any other angles in wheels of unequal diameters.

The cone formation results in the classification of these gears as a type by themselves. It involves two diameters, major, and minor, the first of which is the real or working diameter on which all dimensions are based. The second is dependent on the breadth of tooth face, and is only of importance when teeth have to be cut by rotary cutters. On the outer or major

diameter the same proportions are taken as for spur gears, *i.e.*, pitch diameters, tooth thicknesses, lengths, and clearances. But the circles on which the teeth are struck are not these, but others of larger radius developed therefrom, as in Fig. 196.

Bevel gears are marked out in the following manner:—

The axes A B, A D, Fig. 196, being set out at right or other angles on these, the pitch diameters P D, P′ D′ are marked. Where these intersect at *a*, a line is drawn to the centre A of the axes, which is the apex of the cones, and corresponds with the pitch planes *a*, A of the pair. Lines *b*, *c* are drawn at right angles with these planes, and prolonged until they cut the axes, or centre lines at *a* B, *a* D. Then the lengths of these *a* B, *a* D are the radii on which the curves of the pitch circles *a*′, *a*″ are struck. On these developed circles the lengths of teeth above and below pitch line are marked, and the generating circles are rolled, to produce the curves shown at F and G. In cut gears these also are the radii on which the numbers of the cutters are based. *See* **Bevel Gear Cutting.**

The heights of the teeth above and below pitch lines are prolonged to the common centre A of the gear axes. The lengths are marked by the line *c*, and give the smaller ends of the teeth by direct measurement. It follows that the longer teeth are, the greater will be the difference in their dimensions in major diameters P D, and minor diameters *p d*. The shapes of the teeth on the minor diameters are obtained by precisely the same development as those on the major on the planes projected thence to the axes at C and E, and the pitch planes shown at F′ and G′.

Bevel Gears—Machine-Moulded.—The moulding of bevel gears by machine is done in order to ensure a nearer approach to accuracy of pitch and shape than is usually obtainable by the employment of a pattern. It is also adopted to save the cost of a full pattern. Though the expense of moulding is considerably increased, it does not reach that of a pattern. But if several such moulds are required, the cost of these equals or exceeds that of a complete pattern, and then the question becomes one of relative degrees of accuracy, as well as of relative cost. Speaking generally the place of machine moulding is unassailable when massive gears are in question. The patterns of these would not only be costly, but if made very accurately in the first place, they would suffer distortion in time by usage. Having a true machine, exercising reasonable care in preparing

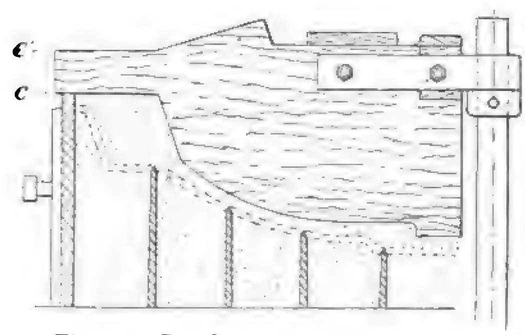


Fig. 197.—Board striking top part directly.

the pattern parts, and in moulding, any number of machine-made wheels will be practically alike. The rivalry of cut gears comes in chiefly in those of small and medium dimensions, and in those which are required in large quantities.

There are several ways by which bevel gears are moulded by machine, depending not only on the forms of the wheels, but also on the methods which exist in different shops. But the essential parts required are striking, or

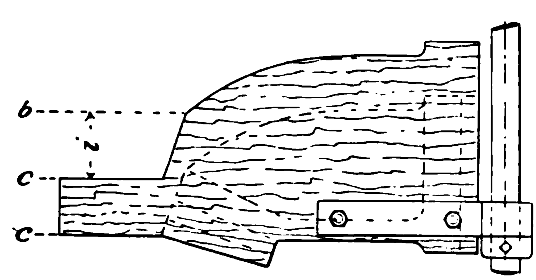


Fig. 198.—Board in position for striking bottom part.

sweeping boards, tooth blocks, and core boxes, with sundry adjuncts and aids, each of which is subject to variations.

The function of striking boards is to sweep up a bed for the teeth and cores, and to form the cope or top part. The general shape of boards is shown in Figs. 197, 198, the board cut for the top striking the top part direct, which in

that case has to be turned over subsequently, in loam mould fashion. An alternative to this is to strike a dummy mould, Fig. 199, and ram the top on that in green sand fashion. The advantage of the latter is that there is no risk of top and bottom not matching, and that no check is necessary for jointing, as there is in the

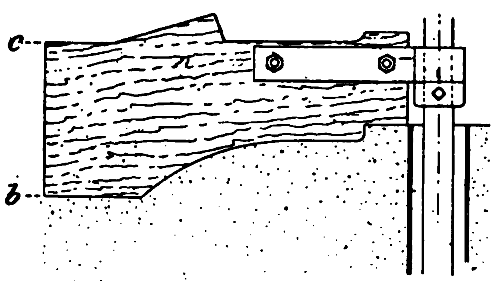


Fig. 199.—Board striking dummy top.

former, provided the bottom is moulded in the floor. It is a method admirably suited for large wheels bedded in the floor, and for any wheels or rings that require facings or bosses or other attachments in the top. These can be laid by measurement in their proper positions on the dummy mould, and the top be rammed over them with less trouble and risk than as though they were measured and set directly into the top.

The same difficulty occurs in machine-moulded wheels, as in those moulded from patterns (*see* **Bevel Gear Moulding**), due to the slight

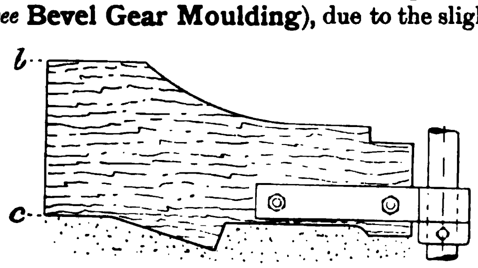


Fig. 200.—Board striking bottom.

amount of bevel at the ends of the teeth as wheels approach the crown form. Thus Figs. 197-201 show alternative methods to adopt. In Fig. 197 the bevel is swept by the board, but in Figs. 199, 200, a space is left between the joints struck by *b* and *c*, equal to the depth of the bevel, which is afterwards filled in with green sand cores, of the thickness *i*, shown in section in the mould, Fig. 201, the depth of which corresponds with the distance *i* in Fig. 198.

The boards for top and bottom may be made separately, or be combined in one, the latter having the advantage of keeping the boards for one wheel indissoluble, instead of risking the getting away of one from the other when put in the stores.

Tooth blocks vary but slightly, the principal difference found being in the number of teeth used, and in the method of cutting. From two to four teeth are employed. Two teeth mould one tooth space; three, two spaces, and four, three spaces. If the number of teeth is increased beyond two, they must be cut most accurately, because not only have the tooth spaces to be considered, but the teeth and their pitch must match absolutely.

The sectional form of the block is that of the teeth, and their end faces only, since the rim

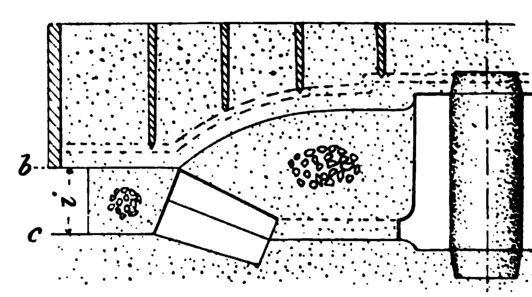


Fig. 201.—Mould Section, with ring of cores.

and the remainder of the wheel are swept by boards, or formed in cores. The hinder portion and top of the block have no formative function, but they must be cut in perpendicular and horizontal planes to receive the carrier of the machine.

Since the block forms a section of the wheel teeth, these are marked out, precisely as though a segment were cut out of a wheel rim, but neglecting of course as just noted the interior portions of the rim. The diagrams, Figs. 202, 203, illustrate this; the section of the tooth block being shown in relation to the section of the wheel rim; and radial, and gauged lines being drawn on each in corresponding positions, rendering the drawings self explanatory. In plan, the pitch, and bevel of the tooth flanks are obtained from a centre line drawn across the

block. A commencement is thus made with a block of cubical shape.

The teeth are variously formed. They are

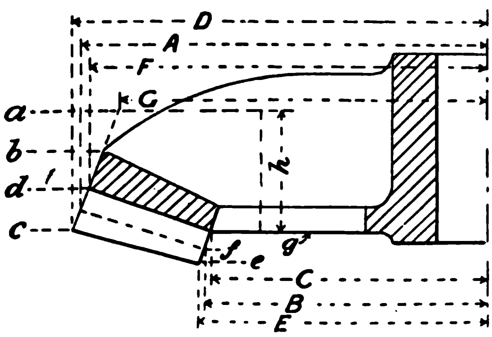


Fig. 202.—Diagram for marking Tooth Block.

cut from the solid,—the grain running in the same direction as the length of the teeth. Or

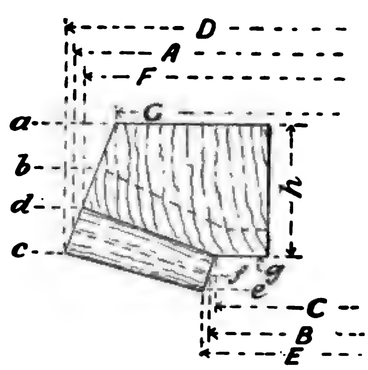


Fig. 203.—Diagram for Tooth Block.

they are glued on a separate block or backing. Or they are dovetailed into the body block in a single piece, which permits of the small fillets being cut in their roots. They are shaped with gouge, chisel, and planes, or they can be planed out in a bevel gear planer when such a machine is available.

Fig. 204 illustrates the gauging of the radial distance of a bevel tooth block, with the radius strip A set between the post of the machine, and the point of the tooth on the small diameter. In Fig. 205 the block has been lowered into position in readiness for ramming. In Fig. 206 a few teeth have been rammed, and the block has been moved round

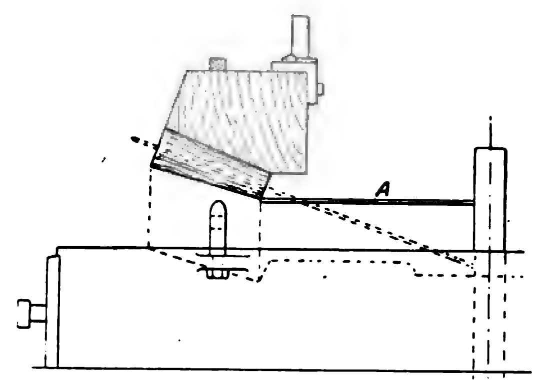


Fig. 204.—Setting the Block.

into a fresh position in the direction of the arrow.

The core boxes, Fig. 207, for bevel gears are as a rule made to suit arms only. If a wheel has a plated centre that is made by sweeping up with the boards which form the outlines of the toothed rim.

The cores occupy the space between the top and the bottom of the mould as swept by the

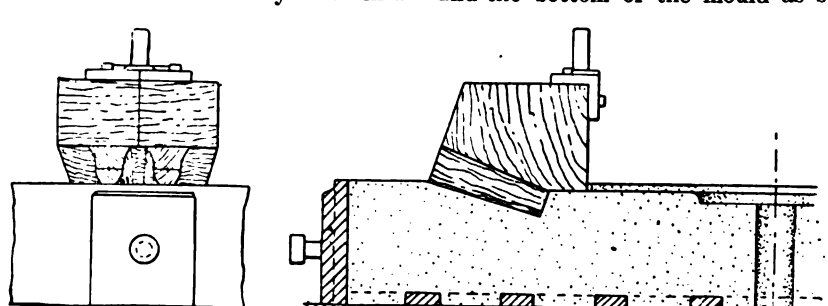


Fig. 205.—Block in position for Moulding.

boards, Fig. 208, which represents the mould commenced by the board, Figs. 197, 198. They are simply laid in place by measurement, the

thickness of the arm and rim spaces being taken by means of thickness strips of wood. The pressure of the top on the cores is usually sufficient to retain them in place. If they are shallow, their security is often ensured by pushing a spike through them into the mould below. Core vents are generally brought out

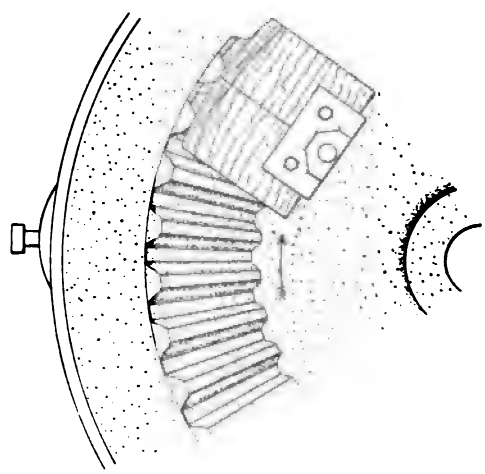


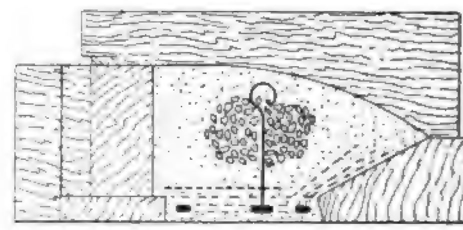
Fig. 206.—Moulded Teeth.

at the top. The cores are rammed on grids with eyes, to permit of lifting them about, seen in Figs. 207, 208.

The foregoing is a concise description of the work involved in a plain wheel. Variations are numerous. Casting friction collars or shroudings on the ends of the teeth does not affect the tooth block, but only the striking boards, or in many cases a ring core, or segmental cores are made to form the collar.

In the case of the smaller pinions, boards may be dispensed with, and time saved by making a block exactly like a blank coming to the tooth points, and ramming this up in the mould instead of striking up, Fig. 209. A hole is bored through the block to permit it to slip over the machine centre bar.

Numerous attachments are cast to wheels, such as other wheels, or pinions, or clutches of claw, or cone type, long bosses and sleeves, brake rings, &c. These are either swept up, or made as separate pattern parts, and bedded in. If



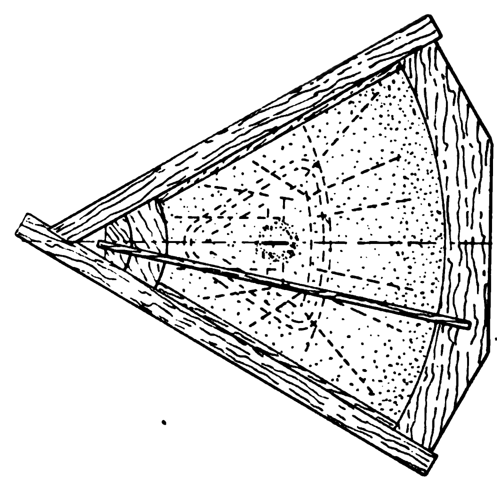


Fig. 207.—Core rammed in its Box.

two wheels are cast together, they are moulded separately, and centred subsequently. In other work, swept up or made from complete pattern

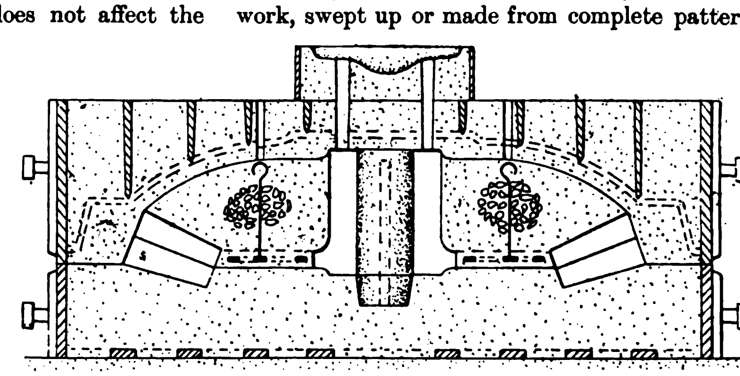


Fig. 208.—Mould of Wheel completed.

parts, exact centring is necessary. Sweeping boards attached to the same machine bar as the wheel boards ensure this. Or in the case of such pattern parts as clutches and bosses, these

are centred by boring a hole in them to fit over the machine bar, similarly to Fig. 209. The machine moulding of wheels other than bevels

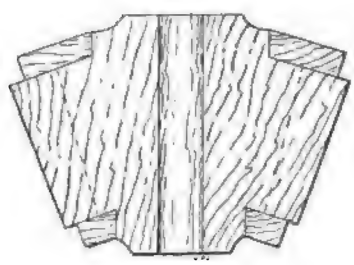


Fig. 209.—Dummy Pattern for Machine Moulding, half shrouded.

will be found described under their proper headings, while the machines will be considered under **Gear Wheel Moulding Machines**.

Bevel Gears—Patterns for.—These are built up in segments, excepting in the case of small pinions, which are made from solid stuff.

Before a pattern can be built up, it must be marked out to full size on a board, and the segment thicknesses marked over it, with necessary allowances in their widths for turning up.

Fig. 210 A shows a rim in section, before its bevels are turned. The first course of segments is glued on the face plate with paper joints, and this and each subsequent course, when the glue has dried, is faced off with a firmer chisel to receive the next one. The correct radius of each course is taken directly by measurement from the board, and a circle run round in the lathe to work by.

Such segments are frequently pegged as well as glued, as a safeguard against the starting of the segments in long service in the foundry. Nails are unsuitable, because in bevelled work they are often liable to foul the turning tools.

The bevels of face and back are turned by the aid of templets, a separate one for each portion, and these are held against a straightedge *a* bridging the diameter, preferably to laying a templet directly against the edge, because the latter would not be so reliable as the broad base afforded by the former. The tooth face is properly done first, Fig. 210 B, though that is not essential; the diameter is struck with trammels set directly from the drawing, and when the turning is done down to that, and to the bevel, as checked by the templet *b*, the wheel body is ready for re-chucking for turning the back.

Variations occur in the rim sections of different wheels. Some have plated centres C, others like that in A, will have arms, but these make no differences in the essential methods here described. Re-chucking can be done on a

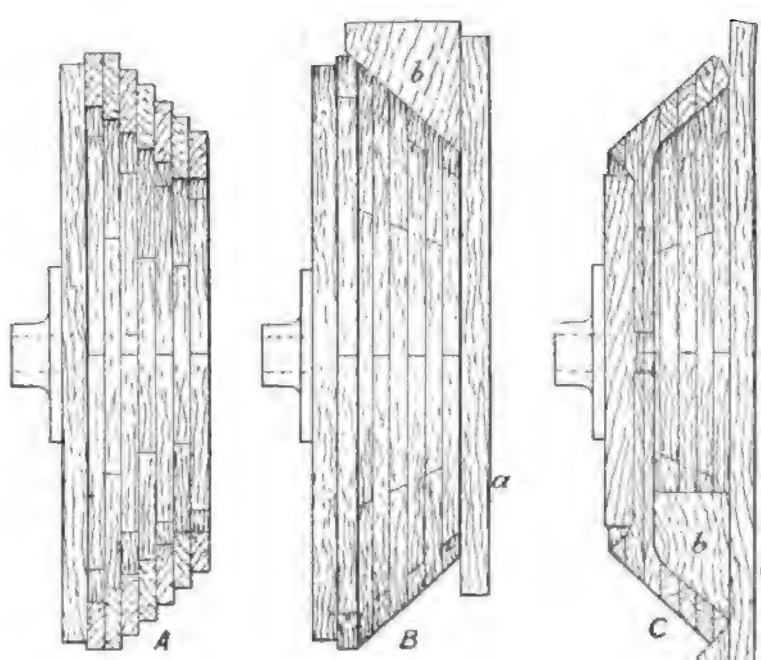


Fig. 210.—Bevel Gear Patterns.

plated wheel by the central hole which receives the boss. In a ring pattern, as in Fig. 210 A, just a shallow groove is turned on the plate to receive the front edge, or three or four pieces of blocking are screwed on the face plate and

turned to receive the wheel rim. The latter in either case is attached by means of screws put in from the back of the face plate.

The interior of the rim is turned by the aid of a templet *b* held against a straightedge *a*, Fig. 210 c, the thickness of the rim being taken by measurement from the drawing on the board.

Before the rim is removed from the plate, two lines are run round on the working face, and close to the edges. On one of these the teeth are pitched out, and subsequently on the other after a perpendicular has been raised with compasses connecting the two, Fig. 211. The centres are then nicked over the edges of the rim with a scribing knife as a guide for the attachment of the teeth.

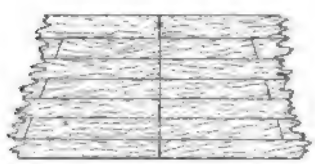


Fig. 211.—Raising a Perpendicular.

At this stage, if arms are required they may be fitted. Whether they fit merely within the rim, or whether they are let in depends on the sectional shape of the wheel. The method of cutting and fitting varies, but the method of locking is the most substantial. Though the webs left by the halvings are thin, they are strengthened by gluing, and may often be reinforced by gluing and screwing a front boss on. The principal boss with its arms is generally and properly left loosely dowelled, for convenience of moulding in the top.

The methods of fitting the teeth vary. They may be glued on the rim as rough blocks, and worked in place, or they may be worked in a box and glued on subsequently. The best method is to dovetail them on as loose blocks, strike them out in place, remove to the bench, and work with planes, and return, and glue them in their places. The most incorrect method is to work them in a box.

Excepting when done by the last-named method, the teeth blocks have to be turned up in place to their correct bevel and length, and to the width corresponding with major and minor diameters. Templets are used here, cut from the drawing like those for the rim. With ordinary care the grain of the ends of the teeth can be turned without being split out by the tools; starting with a chamfered edge, and using a sharp gouge, and taking light cuts. Some, however, glue in strips of wood, between the blocks, and these also often serve the purpose of locations for centres for the tooth curves, avoiding the employment of a loose object for centring on.

Whether teeth are glued on as blocks and marked in place, or dovetailed and planed on the bench, the essential point is to get all the lines of the teeth all pointing exactly to the apex of the wheel cone. The centres are raised by perpendiculars, Fig. 211, or by templet first on the wheel rim, and subsequently on the faces of the tooth blocks at two, three, or more positions nearly equidistant round the rim, and then the spaces between can be pitched out with dividers with little risk of error. The centres are squared over the ends of the teeth by the erection of perpendiculars, or a templet can be used. The tooth thicknesses are marked off from the centres on every tooth, and the curves struck with compasses, which curves are then worked by.

Pinions of small dimensions are best cut from solid pieces of mahogany, or of pine, Fig. 212. But those of medium and large dimensions must be built up, Fig. 213. If the pinions are solid castings their patterns are variously made; as with ring segments, or speaking correctly, cut as sectors, enclosed with true segments at the ends. Or segments may be used throughout. Many pinions have the wheel form, with rim and plate, and then they differ in no respect

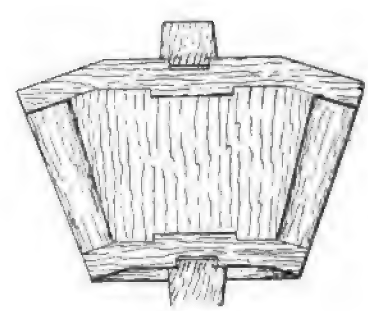


Fig. 212.—Solid Pinion Pattern.

from larger wheels in their method of construction.

Attachments are made to bevel wheels for various purposes. One of the commonest is the shrouding or capping added to increase the strength of the teeth, Fig. 212, or to supply edges, which coming to the pitch line (half shroudings) provide a rolling contact which conduces to steadiness of movement at high speeds, Fig. 213.

All shroudings are left loose from their patterns, the bottom one necessary for delivery, the top for convenience of ramming the teeth. Generally, and with few exceptions, shroudings are built up in segments. They are then turned by similar methods to those adopted in bevel wheel rims. The exceptions occur in small pinions, where they are frequently solid. The bevelled form and fitting of a shroud is often sufficient to retain it in place on the pattern without dowels or skewers; the latter are used on the flatter varieties of wheels. Other attachments are clutches, special bosses, other wheels, &c.

Bevel Gears—Strength of.—This is taken either on the minor diameter, which gives an excess of strength, or at a distance of two-thirds away therefrom, or at the mean diameter, which is a fair average. *See* **Gear Wheels—Strength of.**

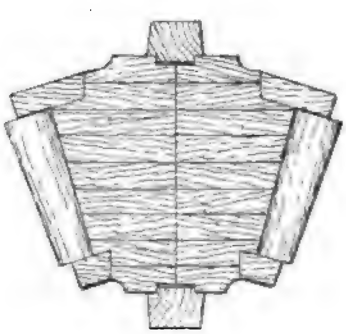


Fig. 213.—Built-up Pinion Pattern.

Bevel Protractor.—This is of value for laying off and for testing angles, and comprises the combination of a protractor with a blade, adjustable to lay against work at any required angle. The graduations on the protractor enable the exact angle to be read off. Fig. 214 shows the Brown & Sharpe type, which has the movable blade attached to a large disc, that rotates upon the stock or base piece. The latter has a circle of divisions, and the disc is provided with a vernier, marked upon the curved strip screwed on. The adjustable blade can be slid through and clamped at any location in the lug of the disc.

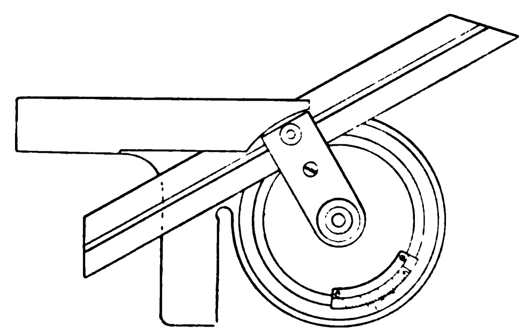


Fig. 214.—Bevel Protractor.

Bib Cock.—A cock having its nose turned down to discharge downwards, as distinguished from the straight-nosed form.

Bicarbonate of Lime.—Carbonate of lime held in solution with an excess of carbonic acid. Carbonate of lime, $CaCO_3$, is practically insoluble in water, but the bicarbonate, $CaH_2(CO_3)2$ is moderately soluble. The second equivalent of carbonic acid is easily removed by boiling, when the carbonate is precipitated, forming a scale. *See* **Feed Waters.**

Bichromate of Potash Cell.—*See* **Batteries—Primary.**

Bick.—The tapered beak or horn which stands out to one end of an anvil.

Bick Iron.—A small anvil made for insertion in the hardie hole of a smith's anvil. It resembles the tinmen's stakes in form and function. It denotes a similar kind of iron used by tinmen.

Bicycle Manufacture.—*See* **Cycle Making Machinery.**

Big-End Brasses.—*See* **Connecting Rod.**

Bight.—The lower looped end of a suspended rope or chain.

Bilge Blocks.—Side cradles used in the slipways of graving and floating docks to

support the bilge keels, as keel blocks sustain the centre keel, and they are carried on the same cradle.

Bilge Injection.—Bilge water is admitted to the condenser tubes through an injection valve of the same area as the sea valve, and is utilised in case of leakage occurring in the hull. The valve is of non-return type to prevent the return of water to the bilge.

Bilge Keels.—Keels fitted outside a ship's bottom flanking the keel proper, their function being to lessen the amount and period of rolling. Since their introduction their proportions have been increased.

Bilge Pump.—Applied to various designs of pumps, the specific duty of which consists in freeing the bilge of a vessel from water. They are of the plunger and clack-valve type, similar to feed pumps, subject to variations, as when they are required also to draw water from the sea in case of fire. Bilge pumps must be able to draw water from either of the compartments of the hull. The suction is therefore connected to the top of a box containing a series of valves each one of which communicates with its own compartment. These are termed bilge directing boxes. Each should have a mud box or strainer for intercepting solid matter.

Bilgram Bevel Gear Cutter.—*See* **Bevel Gear Generating Machines.**

Billet.—Denotes the small bars of square section from which many finished products are rolled in iron and steel works. They are themselves reduced from the larger ingots, and are cut off into lengths suitable for the purpose for which they are required. A billet is smaller than a bloom, the term being restricted generally to dimensions below 6 inches square.

Billeting Rolls.—The roughing rolls for producing merchant iron from billets preparatory to passing them through the finishing rolls.

Billet Mills.—Mills in which steel ingots are rolled down into billets of about 6 inches square. Also the mills in which the cogged blooms are rolled into small billets.

Billet Shears.—The shears used for cutting off billets into lengths after rolling. Lengths of 300 or 400 feet are rolled, and sheared, though sometimes sawn.

Binder Pulley.—A small pulley employed to increase the tension in a short driving belt, which it effects by its pressure on the belt at a position somewhere between the driving and driven pulleys. It should not be employed except in cases of absolute necessity.

Binding Straps.—The plates by which a tool is clamped on the face of a slide rest or of a tool box, by a bolt or bolts passing through holes in the plates. The under faces of the straps are frequently ribbed or cross hatched, to afford a better grip on the tool.

Binding Wire.—Soft iron or brass wire of fine gauge used for tying joints that have to be brazed. The alternative is brazing tongs.

Binomial Theorem.—A binomial quantity, in Algebra, is one consisting of two terms separated by a plus or minus sign, such as $a+b$, $x-y$. The Binomial Theorem is a law (discovered by Newton about 1666) by which any such binomial expression may be raised to any power without the mechanical labour of multiplication. A glance at the expansion of such a quantity as $(a+b)^6 =$

$$a^6 + 6a^5b + 15a^4b^2 + 20a^3b^3 + 15a^2b^4 + 6ab^5 + b^6$$

shows that the powers and coefficients of a and b bear such relations in the successive terms that these relations might be reduced to a definite rule or law. This in fact was known before Newton's days, but only in the case where the power n represents a positive integer. For the development, investigation, and proof of the Binomial Theorem reference may be made to any text-book on Algebra. It will be sufficient here to state the formula and show how it may be applied to expand an expression without the trouble of long and laborious multiplication.

$$(x+a)^n = x^n + nax^{n-1} + \frac{n(n-1)}{1\,.\,2}\,a^2x^{n-2} + \frac{n(n-1)\,(n-2)}{1\,.\,2\,.\,3}\,a^3x^{n-3} + \frac{n(n-1)\,(n-2)\,(n-3)}{1\,.\,2\,.\,3\,.\,4}\,a^4x^{n-4} + \ldots + a$$

Now suppose it is desired to expand $x+a$ to the 6th power, or $(x+a)^6$. Here n equals 6, and it only remains to substitute that number wherever n occurs in the theorem. Thus—

$$(x+a)^6 = x^6 + 6ax^5 + \frac{6.5}{1.2}a^2x^4 + \frac{6.5.4}{1.2.3}a^3x^3$$
$$+\frac{6.5.4.3}{1.2.3.4}a^4x^2 + \frac{6.5.4.3.2}{1.2.3.4.5}a^5x + a^6.$$

Working out the above coefficients we get

$$\frac{6.5}{1.2} = 15;\ \frac{6.5.4}{1.2.3} = 20;$$
$$\frac{6.5.4.3}{1.2.3.4} = 15;\ \frac{6.5.4.3.2}{1.2.3.4.5} = 6.$$

Thus—

$$(x+a)^6 = x^6 + 6ax^5 + 15a^2x^4 + 20a^3x^3$$
$$+ 15a^4x^2 + 6a^5x + a^6.$$

A useful and important fact to be noticed in the Binomial Theorem is that the coefficients of terms equally distant from the beginning and the end are the same. The expansion of $(x-a)^n$ is similar to that of $(x+a)^n$ except that the signs of the odd powers of a, in the 2nd, 4th, 6th, 8th, and other even terms are negative.

Birch, *Betula.*—The birch is a hardy tree which flourishes in humid situations, and in mountainous regions. It attains large dimensions in the alder marshes of Western Russia and Eastern Prussia. There are forests of it in North Scotland. It is cut at different ages according to the purposes it is required for. It is not a wood of great durability. It is used for charcoal for gunpowder, bobbins, herring casks, crateware, wattle rods, brooms, hoops, poles, furniture, and by the wood-turner.

Birds'-Nesting, or Coke Nest.—An annulus of ashes which accumulates on the tube plates of marine boilers round the entrance of each tube. In time the tube becomes closed. These nests can be removed bodily. They occur in trumpet-shaped, or bell-mouthed ferrules, and are believed to be favoured by a red-hot condition of the ferrule.

Birmingham Wire Gauge, or B.W.G.—The origin of this is lost. A gauge bearing date 1795 is, or was recently in existence, while Mr Hughes has shown that the ordinary numbers of wire were in use in 1735 and earlier. It appears to have originated in the requirements of the wire workers themselves, and to have been constructed in a purely empirical manner. Originally employed for iron wire only, it was called the Birmingham iron wire gauge, subsequently it has been used indiscriminately for brass, copper, black steel wire, sheet iron and steel, and for screws.

Originally its dimensions are thought to have been given in 32nds and 64ths of an inch, though now stated in thousandths of an inch, or mils. Mr Latimer Clarke believed the gauge to have originated by calling the largest wire which could be drawn in the days of hand labour No. 1, and the next smaller size which could be drawn at one operation No. 2, and so on; so that the various sizes would be determined by the power of the hand appliances then available for drawing on the one hand, and the cohesive strength of the materials on the other.

In the appendix to the second volume of Holtzapffel's work on "Turning and Mechanical Manipulation," p. 1012, an account is given of the principal gauges then in use, together with a proposal for "an easy and exact system of gages for sheet metals, wires, and general purposes, founded on the decimal divisions of the inch." This scheme, in conjunction with Mr Stubs of Warrington was carried into effect. From a number of gauges he selected the B.I.W.G. proper, the B. sheet metal gauge, and the Lancashire gauge, used exclusively for steel wire, and having shown their want of uniformity, proposed to remove the arbitrary incongruous system of gauges used, and to employ the decimal divisions of the inch and those under their true appellations, and so on. Mr Holtzapffel tested the best drifts in the possession of Mr Stubs and determined the sizes authoritatively, giving them in thousandths of an inch, and these have been adhered to by Stubs since, and are now the best gauges in use.

But unfortunately there are so many other gauges in existence that confusion exists at the present day. In the Report made to the Council of the Society of Telegraph Engineers in 1879, it was stated that the different gauges in use could be counted by hundreds, that every wire drawer had gauges made to suit special objects, that owing to keen competition wire was drawn by one gauge and sold by another, and that half and quarter sizes were

sold as whole sizes, that workmen were paid by one gauge and the wire sold by another, and that as many as seven different gauges have been made between 20 and 21, also that the sheet gauges proper were no less unreliable than the wire gauges. A considerable amount of discussion resulted, various wire gauges were proposed based on geometrical principles, and ultimately, the Board of Trade sanctioned the New Imperial Standard Wire Gauge, whose highest number 7/0 is half an inch in diameter, and whose lowest, 50, is one thousandth of an inch, or one "mil." Even this has not met with general acceptance, for the old B.W.G. holds its own, and will do so probably for a generation or two longer, as do the English measures in face of the metric system. The sizes of the B.W.G. are given in the accompanying table. Gauges are made either circular, or oblong, or elliptical in form. The first are often made as two discs, pivoted together.

No. of Wire Gauge.	Size of each No. in Decimal Parts of an Inch.	No. of Wire Gauge.	Size of each No. in Decimal Parts of an Inch.
0000	·454	17	·058
000	·425	18	·049
00	·380	19	·042
0	·340	20	·035
1	·300	21	·032
2	·284	22	·028
3	·259	23	·025
4	·238	24	·022
5	·220	25	·020
6	·203	26	·018
7	·180	27	·016
8	·165	28	·014
9	·148	29	·013
10	·134	30	·012
11	·120	31	·010
12	·109	32	·009
13	·095	33	·008
14	·083	34	·007
15	·072	35	·005
16	·065	36	·004

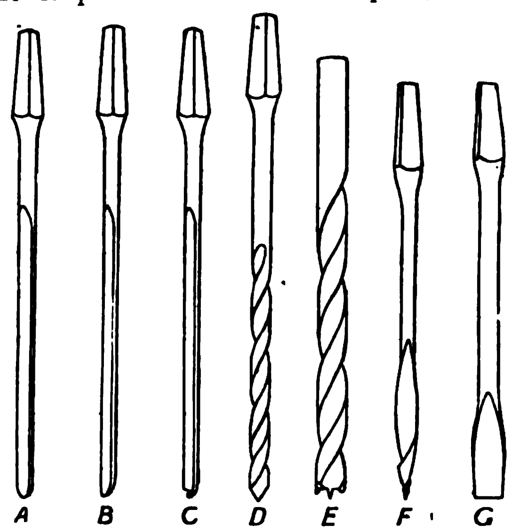
Bismuth, (Bi 206·9), is a hard and brittle reddish-white metal found in the native state chiefly in Cornwall, Devonshire, Cumberland, and Stirlingshire in Britain, in the silver and cobalt mines of Saxony, and in Scandinavia. It occurs also as a sulphide from which it is reduced to the metallic state, crystallising very easily in the form of rhombohedra. Bismuth is unchanged in dry air, but at red heat it forms an oxide, Bi_2O_2 burning with a blue flame; in chlorine gas it takes fire, forming the trichloride $BiCl_3$; hydrochloric acid has scarcely any action on bismuth, but it dissolves readily in nitric acid; it is oxidised in boiling sulphuric acid, liberating SO_2.

Its chief interest in engineering lies in its use as a component of alloys. Bismuth is also valuable for its peculiar property of expanding when cooling; its density actually becomes less when exposed to great pressure, which renders it of value in filling up holes. It is used as an alloy for this purpose, bismuth 1, antimony 2, lead 9. Its melting point is low, 507° Fahr., and with lead or zinc an alloy is formed that will melt at the temperature of boiling water, bismuth 8, tin 3, lead 5; Newton's fusible alloy; or bismuth 2, lead 1, tin 1; Rose's fusible alloy; or a slightly lower melting point than that of boiling water, bismuth 8, lead 3, tin 2. It enters into the composition of pewterers' solders, bismuth 2, lead 4, tin 3; or bismuth 1, lead 1, tin 2.

Bit, *see* Fig. 215.—The term bit is applicable to many boring tools that require a brace for operating them. Brad-awls, gimlets, and augers, are boring tools complete in themselves, and therefore are not bits, which are used either in a brace or in a machine. Held in the first they are generally provided with square shanks, but for use in the second, round shanks are generally preferred, as being more accurate. The diameters of holes that bits are made to bore range from about $\frac{1}{16}$ inch to 2 inches. The kind of instrument used depends on circumstances.

The twist bit, which has become popular, is made in a number of different forms, and for holes of more than about $\frac{3}{8}$-in. diameter is generally superior to any other form made. Every feature necessary for accurate and easy boring is present in this. It is parallel throughout its length, and therefore when once started, cannot deviate from a straight line. It allows ample space for the borings to escape,

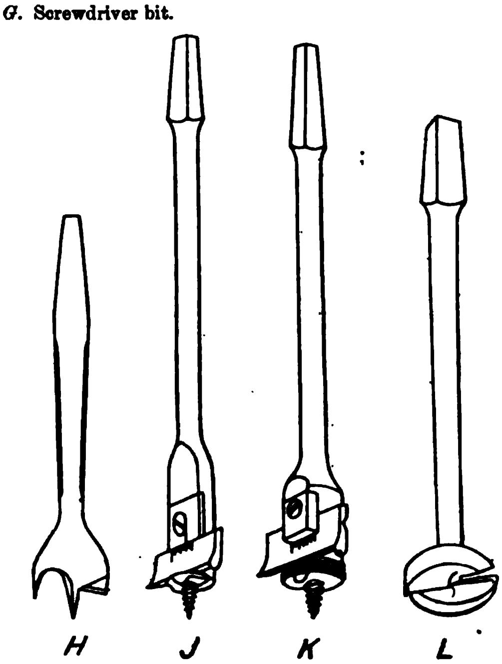
and when withdrawn leaves no borings behind. It is provided with a screw point, which



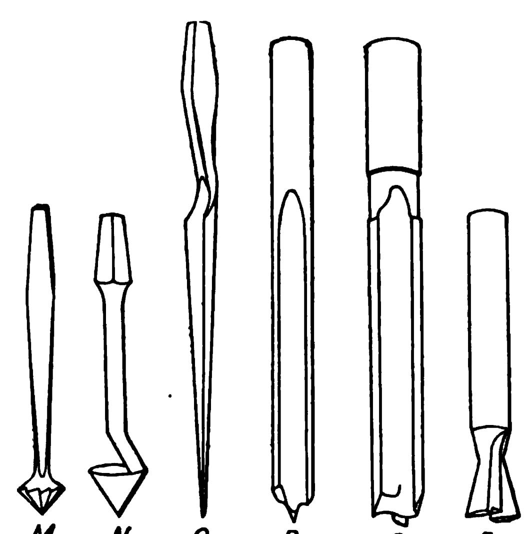
A. Shell bit. *B*. Spoon bit. *C*. Nose bit. *D*. Twist bit. *E*. Ditto with screw and cutters. *F*. Gimlet bit. *G*. Screwdriver bit.

instead of only one cutter as in the old form of centre bit. Otherwise the principle of the latter type is retained in the cutters of the more commonly used twist bits. The centre enters the wood first; then a vertical nicker cuts a ring of the diameter of the bit, and this is followed by the cutter which removes the material by horizontal severance. In the forms of bits which have no projecting nickers for cutting the diameter, the edges have to round up so that they will cut to the full diameter without tearing the wood at the sides. In all forms of twist centre bits, the cutting parts at the end are necessarily rather delicate and easily injured, and may be irreparably damaged by contact with a nail or screw in the wood. They should be kept sharp, not forced too much in hard wood, and used very carefully, or not at all in old work, where there is risk of injury to the bit.

The common form of centre bit which was used exclusively before twist bits were introduced is usually provided with a plain triangular point instead of a screw, but many have the screw tit. The smallest diameter



H. Centre bit. *J*. Expanding centre bit. *K*. Ditto. *L*. Auger bit.



M, *N*. Countersinks. *O*. Reamer. *P*, *Q*. Fluted bits. *R*. Bit for dovetailing.

Fig. 215.—Bits.

enables the hole to be started without difficulty, and renders feed pressure unnecessary. It is balanced by having cutters on opposite sides,

that is of any practical use in centre bits is $\frac{1}{4}$ inch. The sizes most commonly used are from $\frac{1}{2}$ inch to 1 inch. Holes of less diameter

than $\frac{3}{8}$ inch are generally required for screws or nails, and for this purpose other forms of bits are more suitable.

Besides the bits of fixed diameters, those of variable size, called expansion bits, are very useful. These are of the centre bit type, but the cutters are adjustable to bore a hole of any diameter within the limits of the bit.

Bits for boring screw and nail holes are of simpler type. The most common is the shell, which is in the form of a channel sharpened at the end. It bores quickly and cleanly, is not easily damaged, and can be readily sharpened. Its one slight disadvantage is that it cannot be relied to bring the core with it when it is drawn from a hole it has bored. Two other bits, the spoon bit and the nose bit, have been designed to remedy this defect, but they suffer from other defects of their own. The spoon bit, instead of being a straight channel, is curved inwards in the form of a spoon at the end and generally brought more to a point than the shell bit, with the idea of making the point serve as a centre in starting to bore. This curved-in part cuts the core up and pulls all or most of it back with the bit when the latter is withdrawn. The nose bit is provided with a lip or cutter something like a centre bit. This does not penetrate quite as quickly as a shell bit, but it ensures the withdrawal of the core or borings. Another good form of bit for small holes is one of the ordinary twist-drill shape ground rather more acutely at the point. Probably this will ultimately be more generally used than it is at present. An elaborated form of this bit is provided with a centre and two nickers, but like the spoon and nose bits, these complications at the cutting part wear away, and may get broken, and the bit then either has to be discarded or used in its simpler form. Another form of bit not very much used is twisted and pointed in the same way as a gimlet.

Screwdriver bits held in a brace are commonly used and are often more advantageous than a hand screwdriver, being more rapid in action. Countersink bits are generally of the rose or the shell form. The first is generally preferred for use in a brace, as it has a number of cutting edges, and consequently works quickly. The shell countersink has only one cutting edge but it really cuts instead of scraping as the rose bit does. Countersinks with less acute edges are not suitable for wood. Reamers for enlarging holes at their entrance are made in the form of a tapering shell. Large bits, for use in machines, are sometimes fluted instead of twisted, and the cutters are arranged in various ways to do the work required of them. Another form of bit which has some peculiar advantages of its own has its cutting end in the form of a ring, kept central in the wood by its outside, and without the central point that is common to all other centre bits. Bits for dovetailing and other purposes are used in machines specially for the work; and special bits are made for special purposes, such, for instance, as those for cutting hand holes in soda-water boxes. Several twist bits are not illustrated here because they are of the same shapes as the auger bits shown in the group of Figs. 158, Vol. I., p. 224.

Bit Chuck.—A chuck used by wood-workers for holding and rotating carpenter's bits in the lathe. It has a square tapered hole to receive the shanks of the bits.

Bite.—The capacity for holding securely, generally applied to the action of gripping tools and appliances, as pincers, tongs, chucks, &c.

Bit-stock.—A wood-worker's brace.

Bit-stock Drill.—A drill having a square tapered shank to fit a wood-worker's brace.

Bitumen.—An insulating material which becomes softened at a low temperature. To prevent this, it is heated with sulphur, becoming vulcanised, and rigid, without the sacrifice of its insulating property. *See* **Electric Cables**.

Bituminous Coal.—Coal which occupies a position midway between lignite and anthracite. It comprises three varieties, classed by Dr Percy as (*a*) non-caking, rich in oxygen; (*b*) caking; (*c*) non-caking, rich in carbon; and by M. Grüner as (*a*) fat coals, burning with a long flame, or gas coals; (*b*) fat coals, or furnace coals; (*c*) fat coals, burning with short flame, or coking coals. There are no such sharp divisions between them, as they merge and form an unbroken series. The range obtainable renders this group most valuable

to the smith in the gas works, while the non-coking varieties are suitable for the furnaces of steam boilers.

Black Band Ore or **Black Band Iron Stone.**—The term applied to an ore of iron which is highly carboniferous or bituminous. It was discovered by David Mushet in 1801, on the River Calder, and hence for a time termed "Mushet's Black Band," black denoting its colour; due to the presence of so much coaly matter,—from 15 to 25 per cent.—which is sufficient in amount to enable the ore to be calcined without additional fuel, yielding from 50 to 60 per cent. of metallic iron. Extensive deposits occur in Lanarkshire and Ayrshire, and small quantities in North Staffordshire, South Wales, and Prussia. These ores have been a source of wealth to the Scotch ironmasters.

Black Bolt.—A bolt which is screwed on the forged blank without any turning of the shank or machining of the head. Such bolts are used in the rougher classes of work, and as temporary attachments for work in course of erection, plating especially. *See* **Black Fit.**

Black Copper.—"Fine metal," *see* **Copper.**

Blackening or **Blacking.**—Finely-ground plumbago, or charcoal, used for dusting the surfaces of ironfounder's moulds.

Black Fit, denotes the opposite of close fitting, whether effected either by hand work, or by machine. It means that the work is put together just as it leaves the foundry, or the smithy; rough-cast, or rough-forged surfaces coming into contact.

The economics of this method of fitting diminish as the cost of machining is gradually being lessened. The practice of making black fits is largely a survival from the time when fitting was mainly effected by hand; and later, when it was performed to a great extent in machines that were inefficient by comparison with those of the present time.

But there is another side to the subject, since there are large groups of machinery for many parts of which, for practical purposes, black fits are quite as suitable as bright. And in these the employment of the first-named does not lessen cost, but rather the contrary. The reason for this apparently contradictory fact lies in the better facilities which now exist for making castings and forgings to precise forms and dimensions, the first by the use of moulding machines, the second by the employment of dies or stamps for forgings. These therefore favour the practice of making black fits in those mechanisms for which they are suitable, while the cost of bright fits in other cases is lessened by machines and methods which are of comparatively modern growth.

Black Hole.—A hole which is cored, or forged, as distinguished from one that is drilled or reamered.

Black holes are used because it costs less to core than to drill. The objection to them is that close-fitting bolts cannot be inserted. A cored hole that has to be subsequently enlarged by drilling or reamering does not come under this head, but only those which are left as cored.

Around this question of cored *versus* drilled holes, much difference in practice and opinion exists. There are of course an immense number of cases in which there can be no difference of opinion, since in high-class work black holes are wholly inadmissible, while in a cheap rough class of machinery they are as suitable as drilled and reamered holes. But much lies on the border line, and then differences of opinion come in. The subject may be considered from two points of view, relative cost, and efficiency of results.

First as to cost. This question stands differently now from what it did a few years ago. Drilled holes can be made much more cheaply than formerly, because machines have been speeded up, and heavier feeds are taken. And in cases where holes have to be drilled on work in course of erection, the numerous portable machines are now available, ousting the John Bull and hand work. Some holes again are much more cheaply made than others. Thus shallow holes may be drilled, while coring may be adopted in deep ones. But there is another aspect of the case, which is this, that the direction of the holes makes a great difference, both in cost and in the degree of accuracy obtainable. Vertical holes are the most readily cored, horizontal ones are more expensive, and give more trouble, while those

which run diagonally are the worst to core. This does not imply that there is any difficulty in either, but that more work is involved, and risks are run of displacement of the cores, which have to be guarded against. Vertical holes are carried in round prints, but horizontal ones require drop, or pocket prints, diagonal holes must have a top stay print, or else chaplet nails. Short cores are rigid enough in themselves, but long ones are liable to become bent by the pressure of metal, especially when they are laid horizontally, and all these things have to be taken account of in settling the use of black holes in preference to drilling. *See* **Core Prints**.

With regard to efficiency of results, the place of black holes lies in those cases where clearance is permissible. In these the bolt is a means of union, regardless of the chances of side slip of the parts united. But when the necessity arises for the prevention of all chance of side slip, as in parts which are subject to much vibration, the turned bolt in a reamered hole is the proper means of union to adopt.

There are, however, numerous cases in which a compromise is made. When there are several holes in a piece of work, and these are of considerable depth, some are drilled for closely fitting bolts, and others are left black. Such strain as there is then tending to side slip is taken by the turned bolts, while the black fitting bolts simply act as means of union. Often again the steadiness of the parts is assured by closely fitting machined tongues or registers, or side bearing strips, in addition to the bolts.

Blacking.—*See* **Blackening**.

Blacking Bag.—A muslin bag containing ground plumbago or charcoal, from which the dust is shaken over a mould, passing through the interstices of the muslin.

Blacking Mill.—A rotary mill in which blackening is pulverised. It is a cylinder with rollers, or a ball mill.

Blackleading.—This is often applied to patterns to impart a very glossy skin which is favourable to clean delivery. In the case of those of wood, two or three applications of shellac varnish are necessary first to close up the grain and harden the surface. In iron patterns, the surface is rusted first. In brass no previous preparation is required. The blacklead is applied with brushes just as to a grate.

Black Nuts.—Nuts which are left as forged, and not machined on the flats or faces.

Black Oils.—Crude mineral oils, used largely for cylinder lubrication.

Black Oxide of Copper.—*See* **Copper**.

Black Plates.—*See* **Tin Plates**.

Black Sand.—The ordinary sand which constitutes the floor of a foundry is so termed. It acquires its blackness by repeated use. It is constantly receiving accessions of new sand from the moulds, and being watered, otherwise it would be of the nature of **Burnt Sand**. It is used only for box filling, and for the roughest class of moulds. Ordinary castings are poured against a stratum of new sand, a kind of lining to the box filling, hence termed **Facing Sand**.

Blacksmith.—*See* **Smith**.

Black Smoke.—*See* **Smoke**.

Black Varnish.—This is used for patterns as an alternative to the yellow shellac varnish. It is made by mixing lamp black with the latter to impart a rather harder skin to the wood, or more frequently to distinguish core prints from other portions.

The best regular black varnish is made by dissolving black sealing wax in spirit, 3 lb. of black sealing wax, and 1 lb. of shellac to the gallon. Or fine lamp black may be mixed with brown hard varnish, or lacquer. Another is made by fusing 3 lb. of asphaltum, and adding $\frac{1}{2}$ lb. of shellac, and 1 gallon of turpentine.

A black varnish for ironwork is made thus :—1 lb. of asphaltum, $\frac{1}{4}$ lb. lamp black, $\frac{1}{2}$ lb. resin, 1 quart spirits of turpentine, with sufficient linseed oil to rub up the lamp black before mixing it with the other ingredients.

Black Wash.—A wash for the faces of foundry moulds, made by dissolving ground charcoal, coal, or plumbago in clay water, to be applied with a brush, and afterwards dried. Often termed Wet Blacking.

Blanchard Lathe.—*See* **Copying Lathe**.

Blank.—Any piece from which an element

of mechanism is to be fashioned, as a wheel blank.

Blank Bolt.—A forged piece not yet screwed.

Blank Cap.—A cap which is screwed on the end of a hose pipe when not in use.

Blank End.—The end of a pipe or cylinder across which metal is cast, instead of being left open.

Blank Flange.—A flange which is a solid disc, and thus closes the end of a pipe to which it is bolted. This is more convenient than casting the ends of a pipe solidly, besides which it can be removed at any time, and other lengths of pipe attached for the purpose of making extensions.

Blank Holes.—Denotes holes which end in a *cul-de-sac*, distinguished thus from thoroughfare holes. The difference between the two becomes of importance in tapping screw threads, which can only be screwed to the bottom of blank holes with the third tap in a set, termed the bottoming tap, because it has full threads right to the end. Also denotes rivet holes which do not coincide by a distance equal to their own diameter. These are also termed Blind Holes.

Blanking, Blanking Die.—The operation of cutting out blanks is a common one both in sheet metal and in regular forging work. The blanks may be either used as they are, or be machined subsequently, or bent and shaped into more or less intricate forms in other dies. The simplest kind of blanking is that of punching out washers; such work is best done from a long strip of metal fed up to a stop at the back of the die, so that the pieces are knocked out rapidly, and with the least waste of metal.

The die is most conveniently held in a bolster, because this affords a means of readily accommodating a variety of dies, as may be necessary for different work. The bolster is a plate bolted to the table or bed of the press, and having a grooved recess at the top, in which the die is pinched by means of set screws. A hole in the base of the bolster allows the punched blank to fall clear through.

The amount of clearance given to a blanking die from the cutting edge backwards may vary from one to four or five degrees, depending on the amount of service which will have to be endured. Less clearance is often given if a great number of pieces have to be produced, so that the die may keep its size for a longer period. The play or space between die and punch varies with the thickness of metal to be blanked; in very thin material the clearance must be unappreciable, otherwise the metal will turn out with bad and rough edges. In thick stuff some play between punch and die is necessary, which may range up to $\frac{1}{32}$ or $\frac{1}{16}$ inch. A point which may be noted as to tempering concerns this clearance. For large blanks in thin stuff the punch is usually left unhardened, so that when worn it is small, and consequently turns out ragged blanks; it may be hammered or upset around the edge, so bringing it up to size again. The die should always be hardened; the punch may not always be, as in this instance.

Although small blanking dies work successfully without any shear being imparted, the larger sizes are best constructed with a bevelled, or a wavy edge, so that the sheet is cut in detail, with less effort, and less distress to the material.

To maintain the cutting edges of punches and dies in efficient condition grinding is resorted to. The faces of dies are often sloped away, leaving a rather narrow ledge around the aperture, upon which ledge the grinding is effected.

The use of a lubricant enables blanking dies to work better than when dry. The oil, grease, or soapy water can be applied either in the case of the first two, to the whole sheet or strip before feeding between the dies, or it may be allowed to drip on just before blanking.

The determination of the dimensions of a blank which has to be subsequently cupped or bent into a more or less difficult outline is largely a matter for trial and experience, since there is compression or extension of the metal, the amounts of which cannot be accurately gauged. The practice therefore is very often to cut sample sheets, and perform the bending operations, so ascertaining the correct size of blank from which the blanking die is made. Frequently an exact estimate of the blank area is unnecessary, as when subsequent trimming

or clipping is done upon the edges of a cupped or drawn piece, the blank being consequently made sufficiently larger to allow of this finishing off.

A method of getting the area contained in the surface of a piece is by mensuration, making the blank to suit. This is rather troublesome in the case of difficult pieces, and here experience with previous work of a similar character is a great help to the die-maker; in fact sometimes the blank dimensions can be got at by comparison with almost identical specimens made for former jobs, a little allowance one way or the other being made to suit the new article.

The gravitative method of getting at blank sizes is possible when a specimen piece of work is available. The latter is weighed, and a piece of sheet of the specimen thickness and one inch square also weighed. The weight of the sample is divided by that of the square inch of sheet, and the result gives the number of square inches which must be contained in the blank area. If, however, subsequent cupping of the blank in further operations results in stretching of the material, this method is not applicable.

Blanking Press.—The machines employed for the operation of blanking dies are also used for other processes, as bending, cupping, turning round, &c. For large thick blanks in steel or iron the regular die-forging presses are necessary, either drop or hydraulic. References will be found under the headings referring to these various types, and also under **Power Press.**

Blast.—Denotes generally a current of air produced by pressure, which is stated in ounces or pounds per square inch, or in inches of head of water, or of mercury. Pressure is measured by gauges, and sometimes is registered by autographic diagrams. These are recorded on a paper diagram wound on a cylinder rotated by clockwork, once in twelve or twenty-four hours, and the movements of the spring of the pressure gauge are communicated to a pencil pressed against the cylinder as well as to the pointer on the dial. Blast plays a most important part in the supply of air to the furnaces of steam boilers under the term "draught," to furnaces used in metallurgical processes, to the ventilation and warming of buildings, and the ventilation of mines. Blast is cold, warm, or hot; it is produced positively by blowers, or by fans, or by the natural draught of tall chimneys. Its employment has been the means of creating great fields of engineering work. These applications will be found treated under their suitable heads, but the present article will deal chiefly with the properties of air under pressure, and the methods by which it is estimated.

As positive pressure, or forced movement of the air is essential to produce steady blast, we have three typical mechanisms for producing it, the **Blast Engine**, the **Blower**, and the **Fan**, each adapted to different duties and conditions. However produced, the blast behaves alike in its transmission through pipes. So many cubic feet per minute have to be moved at a velocity of so many feet per minute, and these velocities correspond with certain pressures per square inch. Mr Hawksley's formulæ are given below.

$$V = 396\sqrt{\frac{h\,d}{l}}$$

$$h = \frac{l\,v^2}{156{,}800\,d}$$

Quantity of air delivered per second.

From a pipe, $Q = 311\sqrt{\frac{h\,d^5}{l}}$

From a passage of any section, $Q = 796\sqrt{\frac{a^3 h}{c\,l}}$

Where V = velocity in feet per second.
h = head or drag in inches of water.
d = diameter of pipe in feet.
l = length of pipe or passage in feet.
c = perimeter in feet.
a = sectional area of pipe or other passage in square feet.
Q = quantity of air discharged in cubic feet per second.

But dimensions obtained thus are of little more than very general utility, because they do not take account of the features of particular cases. A comprehensive rule is:—Divide the air required per minute by the velocity, which gives the effective area, and then add a safe percentage for friction.

Round pipes produce least friction. Square ones come next, and the nearer pipes of rectangular section approach the square form the better. Branches should not come off at right angles, but at 45°, with an easy radius. Bends should be struck with a good radius of not less than the pipe diameter. To facilitate practice, tables are prepared by firms of the diameter of pipes required for given volumes of air at stated velocities, based on the fact that the loss of pressure from this source increases directly as the length of the pipe, and as the square of the velocity of the moving air. As these are generally based on the firm's own experience they are safer than mere formulæ.

Inefficiency often results from neglect of proper pipe diameters suitable for great lengths, and by the introduction of quick bends. Thus, as lengths increase the pipe diameters must be increased to compensate for friction. Again, extensions should be made on main pipes, and not on small branch pipes, in which the friction is greater. It is not therefore a question of combined area, for experience proves that this is very misleading. Thus the combined area of nine 6-inch pipes is equal to that of one 18-inch pipe, but sixteen 6-inch pipes would be required to do the work of one 18-inch.

Having designed the pipe arrangements for blast, means of measuring it are often required. An anemometer measures the velocity. It takes the form of a delicate fan put in the blast passage, the rotation of which is transmitted to gearing, and registered on the face of a counter in feet per minute, in an ascending series of units. The velocity thus registered, multiplied by the area of the passage gives the total volume of air moving.

The blast gauge measures the pressure. It is connected to the pipes, and the pressure of the blast is indicated by the difference in level of the water or mercury used in the gauge. If in inches of water it may be read as ounces, by multiplying by 0·578, this representing the equivalent in ounces of the pressure due to a head of one inch of water.

Blast Box. — The box underneath a Bessemer converter through which the blast passes from the belt and pipe on its way to the tuyere holes.

Blast—Dry-air.—The use of dry-air blast, though not a new idea, is nevertheless only lately being attempted in regular working at the Isabella furnaces of the Carnegie Steel Company in a suburb of Pittsburg, where the installation has given much satisfaction.

The following table shows the varying quantity of moisture in the air as taken by the United States Weather Bureau at Pittsburg:—

	Average Temperature.	Grains of Water per Cubic Foot of Air.	Gallons of Water entering per Hour into a Furnace using 40,000 Cubic Feet of Air per Minute.
January	37·0	2·18	87·2
February	31·7	1·83	73·2
March	47·0	3·4	136·0
April	51·0	3·0	120·0
May	61·6	4·8	192·0
June	71·6	5·94	237·0
July	76·2	5·6	224·0
August	73·6	5·16	206·4
September	70·4	5·68	227·2
October	56·4	4·0	160·0
November	40·4	2·35	94·0
December	36·6	2·25	90·0

The second table is one taken at the furnaces at 9 A.M.:—

	Grains of Water per Cubic Foot of Air.
January	2·8
February	2·7
March	3·1
April	3·3
May	4·7
June	7·3
July	7·0
August	7·1
September	5·4
October	3·2
November	3·3
December	3·0

These changes are not uniform, but vary from day to day. And experience of working shows that these sudden changes produce greater irregularities in blast-furnace working than the mere hygrometric condition alone, because of the margin of heat necessary to compensate for these variations.

At the furnaces just named an ammonia refrigerator plant has been installed to absorb the moisture from the air. The air deposits its moisture in the form of water or frost on the brine coils, and passes to the blowing engines at a temperature of freezing or below, and with a practically uniform amount of moisture. In a fortnight after its installation, the burden was increased by 20 per cent., and the coke consumption was lessened.

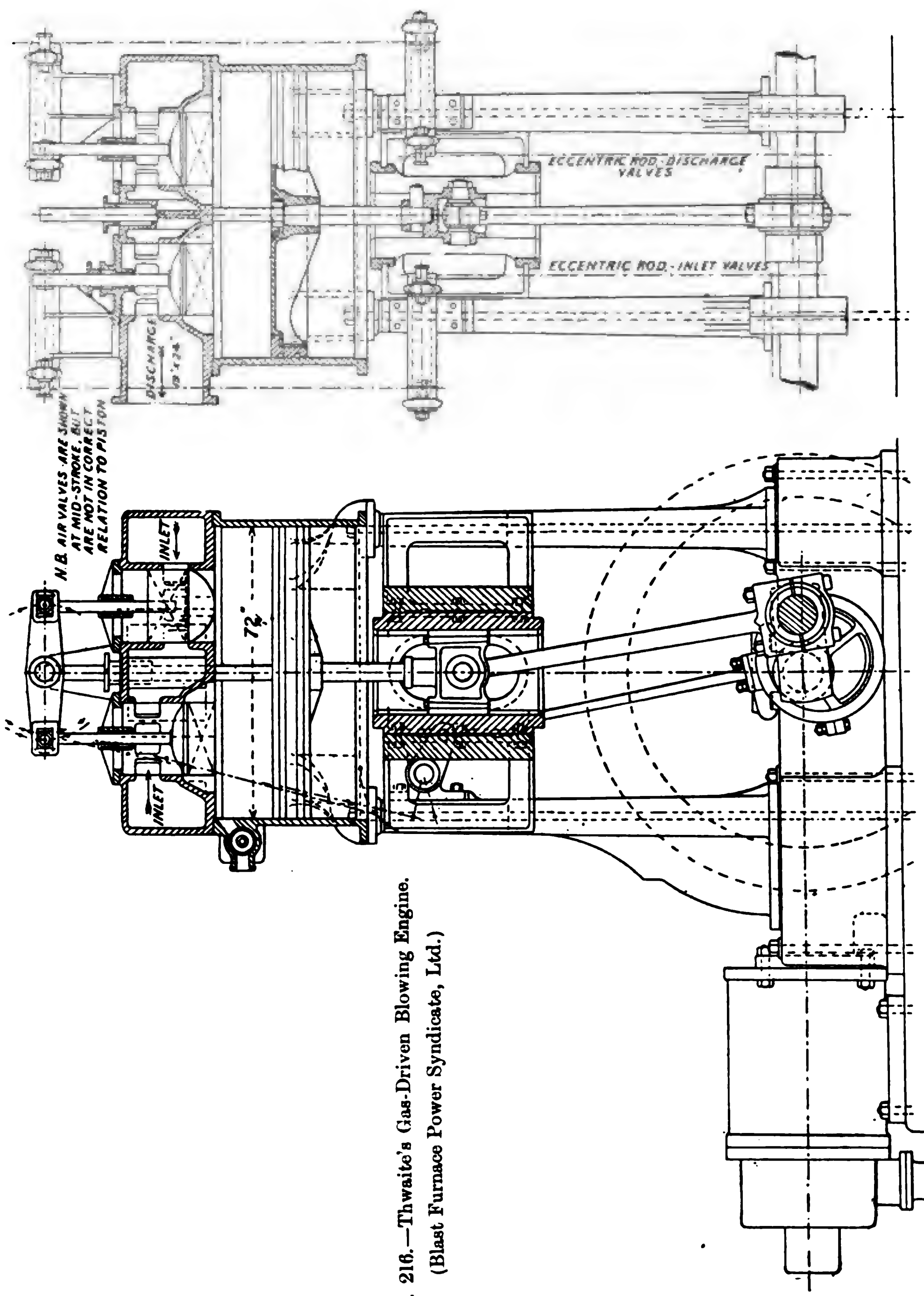
Mr Gayley has given a number of figures showing the results from day to day. Summed up they amount to this, that without dry blast the average daily product of pig from 1st to 11th August was 358 tons, with an average daily expenditure of 2,147 lb. of coke. But that using dry blast, the average daily product from 25th August to 9th September was 447 tons, on an average daily expenditure of coke of 1,726 lb. There was further a very great economy in engine power. It became necessary to reduce the revolutions of the blowing engines due to the tendency to drive the furnace too fast. Before applying the dry blast, the engines were running at 114 revolutions, and supplying 40,000 cubic feet of air per minute. The speed was reduced to 96, and then they produced 89 tons more pig in twenty-four hours, with a gain of 150° in the temperature of the blast. With moist air the engines indicated 900 IHP., with dry blast the average was only 671, a clear saving of 229 IHP. per engine, or 687 IHP. for the three engines.

Blast Engines.—To provide air for the rapid combustion of the fuel in the iron smelting or "blast" furnace, large and powerful engines are necessary, since the volume of air required is great. Thus for a furnace capable of producing 125 tons of iron per twenty-four hours, no less than 20,000 cubic feet of air per minute must be discharged at a pressure of 5 to 10 lb. per square inch, and for this a blowing tub of 96 in. diameter by 60 in. stroke, run at 40 revolutions per minute by a 48-inch steam cylinder will be required. It is of great importance that a furnace should be provided with sufficient blast power, and there should always be a few revolutions in hand, so that more air can at any time be provided in case of need. In this country the blowing engine is usually and indeed almost invariably of vertical form, with the blowing tub or air cylinder placed high up and carried by vertical standards, and the steam cylinder below on the base plate. A crosshead is carried on the piston rod between the cylinder and the tub, and connecting rods descend from this at each side to take hold of pins in the flywheels, of which there are two, the shaft which carries them extending under the steam cylinder.

The ratio of diameter of steam to air cylinder is usually 1 : 2, or nearly so, and the speed 45 to 55 revolutions per minute. In Continental practice it is more usual to employ horizontal engines and blowing tubs, the latter behind the cylinder. Such an engine by the Meuse Engineering Co., has two side by side steam cylinders on the compound principle, working two cranks with an intermediate flywheel. The steam cylinders are 39⅜ in. and 63¼ in. diameter respectively (*i.e.*, 1000 and 1606 mm.) with a stroke of 4 feet 11 in., or 1500 mm. at 42 revolutions per minute. The air tub is 84¾ in. diameter, equal to 2150 mm., and the output is 32,760 cubic ft., equal to a furnace capacity of 234 tons. The air pump and condenser are placed in the foundation.

Of late years the blowing engine has been often worked by blast furnace gas, and in this direction also there has been a tendency among Continental engineers to employ the horizontal form. Thus in a gas-driven blowing engine of the Cockerill type, there are two 51¼-in. diameter gas cylinders, driving tandem fashion a single 73-in. blowing tub with a stroke of 55 in., and a speed of 60 to 80 revolutions per minute, at a pressure of air of 10 to 15 lb. This engine is made in this country by Richardsons, Westgarth & Co., Ltd. The general practice, however, in Great Britain and America is to use vertical blowing tubs.

In the gas-driven blowing engine on the Thwaite system, Fig. 216, at the works of the Clay Cross Co., near Chesterfield, the gas or power cylinders are horizontal, and the blowing tub is vertical. The gas cylinders, two in number, have a diameter of 27 in., and a stroke of 30 in., and they work on the Otto or four-stroke cycle at a speed of 160 revolutions per minute. The ignition is by tubes, two in



Sectional Elevation through Discharge.

Sectional Elevation.

Fig. 216.—Thwaite's Gas-Driven Blowing Engine. (Blast Furnace Power Syndicate, Ltd.)

number, so that one can be changed while the other continues the work. The blowing tub, supported on four columns, has a diameter of 72 in., and a stroke of 28 in. The piston speed is high, 760 ft. per minute, and the capacity 10,000 cubic ft. of air per minute. There are two inlet valves 18 in. diameter, and two 18-in. diameter discharge valves in the cylinder head. The valves are positively driven, and are of the sleeve variety, and the tub is single acting, the bottom end of the cylinder being open.

Since the gas cylinders are horizontal and the air tub is vertical, the working stroke of the gas cylinders is available for the final half of the air piston compression stroke, and in this way the general mechanical efficiency is best secured. Both the gas-engine cranks point the same way, and are nearly at right angles to the air-tub cranks.

The main features of the air tub are the short stroke and high speed, and the peculiar sleeve valves which are carried on short double-ended rocking levers on the top of the tub, the levers being rocked by an eccentric and rod gear from the crank shaft. *See* Fig. 216. The gas cylinders are scavenged from the blast main, and the engine is set to work by means of a small auxiliary gas engine, with a friction drum driving upon the flywheel.

In a later design of engine the air valves are of Corliss type in the head castings of the air tub, which is double acting, and there are two central flywheels carrying the driving pin of the air tub between them.

The Thwaite system has been adopted for the blowing plant of the Lackawanna Iron Works, Buffalo, U.S.A. In this plant, horizontal Körting gas engines drive a vertical blowing cylinder. There are two gas engines to each blowing cylinder. The air cylinders have balanced sliding valves, they are each 76 in. diameter by 60 in. stroke, and are designed for 80 up to 90 revolutions per minute, and to blow up to 30 lb. air pressure.

By means of the sliding valves the air clearance is reduced to $1\frac{1}{2}$ per cent., and the discharge valve only opens when pressure is equal on each side, so there is very little work involved in its movement. It is worked by an air cylinder attached to the valve spindle, but there is also a positive motion in case the air cylinder acts too slowly. Owing to the greater speed of gas-driven engines the air valves require special attention. The Cockerill Co. use flat spring-loaded discs for ordinary low pressures. The Southwark Foundry Co. use a balanced sliding grid valve, and this is fitted to the Lackawanna engines.

Fig. 217, Plate XII., shows a fine set of engines in which the special feature is the application of the "Southwark" valve gear to the air cylinder. The inlet valves are placed at the bottom of each end of the cylinder, and are positive in action, being worked by links and eccentrics on the side shaft. The air outlet valves are placed above the inlet valves, and are connected to a piston working in a small cylinder, one side of the piston being in connection with the air cylinder. When the pressure in the latter equals the pressure in the main, the piston is forced out, and the valve is opened. The closing of the outlet valve is also positive, and is effected by means of a second smaller piston, placed in front of the other piston, and worked by a rocking lever coupled to an eccentric on the countershaft.

A special advantage of this arrangement is that higher pressures can be blown when required. This is effected by the inlet valves being kept open for a part of the return stroke, the reduced volume of air being then compressed to the amount required. There is a second shaft, which carries at each end a short lever, and the end of each of these levers forms a pivot, on which the inlet eccentric is suspended. The relative position of the levers controls the angle at which the eccentric swings, and in this way an earlier or later closing of the inlet valve is obtained. The second shaft referred to is in turn controlled by a smaller piston working in an oil cylinder, the valve of the latter being operated by the action of the blast which presses against a spring-loaded piston. The pressure can be increased or decreased by hand, as required to suit the pressure of air desired. *See also* **Blast Furnace Gas Engines**.

Large gas-driven blowing engines consume about 100 cubic feet of blast-furnace gas per

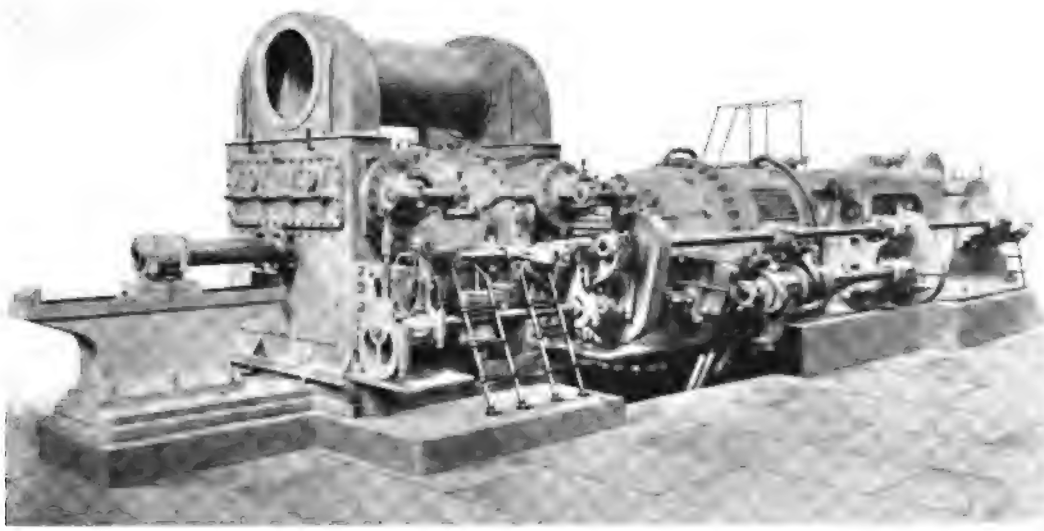


Fig. 217.—Gas-Driven Blowing Engine, 750 HP. (Richardsons, Westgarth, & Co., Ltd.)

Fig. 223.—Installation of Gas-Driven Blowing Engines (Cockerill type).
At Cargo Fleet Iron Co.'s Works, Middlesbrough. Total, 5,600 HP.

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brake HP. hour, about 76 feet of producer gas, and about 32 feet of coke-oven gas. An 800 HP. engine used 5 gallons of oil per twenty-four hours. Mazout of special quality will do, and some of it can be used again after filtration. About 12 to 14 gallons of water per brake HP. hour must be passed through the jackets. About 3 per cent. is lost by evaporative cooling.

Blast Furnace.—The modern blast furnace differs from the ancient furnaces in the fact that the product is well under control, and is always cast iron, instead of an uncertain product which partook more of the character of malleable than of cast iron. The blast furnace dates from about the beginning of the sixteenth century, but its true era came with the successful utilisation of coke by Abraham Darby, about 1733. In 1740 the production of British pig was only 17,350 tons, in 1796 the annual make per furnace was only 1,032 tons, or less than 20 tons a week. From 1804 to 1818 the price of pig ranged from £7 to £9 per ton. In 1828 the hot blast was introduced. With the introduction of the fire-brick regenerative hot-blast Cowper stoves (1860) the economy was increased. Later, Whitwell's apparatus for heating the blast effected further saving. Also the height and capacity of furnaces grew. Sir Lowthian Bell gave the following figures:—

Date.	Blast Furnaces.	Weekly Make.	Coal per Ton of Iron.
		Tons.	Cwt.
1835	Height 40 to 50 feet, capacity 5,000 cubic feet, blast cold	70	120
1845	Height 40 to 50 feet, capacity 5,000 cubic feet, blast at 650° Fahr.	120	85
1855	Height 40 to 50 feet, capacity 5,000 cubic feet, blast at 800° Fahr., and using the escaping gases for steam and hot air	220	62
1865	Height 80 feet, capacity 20,000 cubic feet, blast at 1,000° Fahr.	450 to 550	40

These figures have been increased since as will be seen in this article.

At the Edgar Thomson works there are furnaces 91 ft. high, having 20-ft. boshes, with an angle of 75°, a throat 16 ft. diameter, crucible 13 ft. diameter, tuyeres 8 ft. 6 in. above the level of the hearth, projecting 6 in. within the lining, and having nozzles 8 in. diameter. The output is 11,000 tons of pig per month, using ores containing 62 per cent. of iron.

At the Duquesne works, there are furnaces 100 ft. high, boshes 22 ft. diameter, angle of bosh 74°, throat 17 ft., crucible 14½ ft., bell 12½ ft., ten tuyeres 8 in. diameter, placed 9 ft. 8 in. above the level of the hearth.

The Youngstown furnaces of the National Steel Co., blown in in 1900, are 106½ ft. high, 23 ft. diameter in the bosh, 15 ft. in the hearth.

Blast furnaces vary much in shape and proportions, which cannot be satisfactorily explained on a theoretical basis. There are national and local differences, in the ores, fuels, and fluxes used, in blast pressure, in slow or rapid working. As the ores smelted vary much in percentage of iron, the poorer ones require a larger furnace capacity than the richer ones, and at the same time the furnace yield is less.

The best guide for the shape of a furnace working under any given conditions is obtained after one has been blown out. The lining will be found to have worn more in one locality, and have received deposits in others. Thus the original form may be modified with advantage.

Although the tendency has been to a regular increase in height and diameter as being conducive to economical results, yet a limit comes to this in the capacity of the fuel to withstand crushing, hence the high furnaces must burn hard, strong coke, and not weak coke, or anthracite coal.

The parts of a blast furnace are the following, beginning at the top, and considering only the modern or cupola blast furnace closed with a

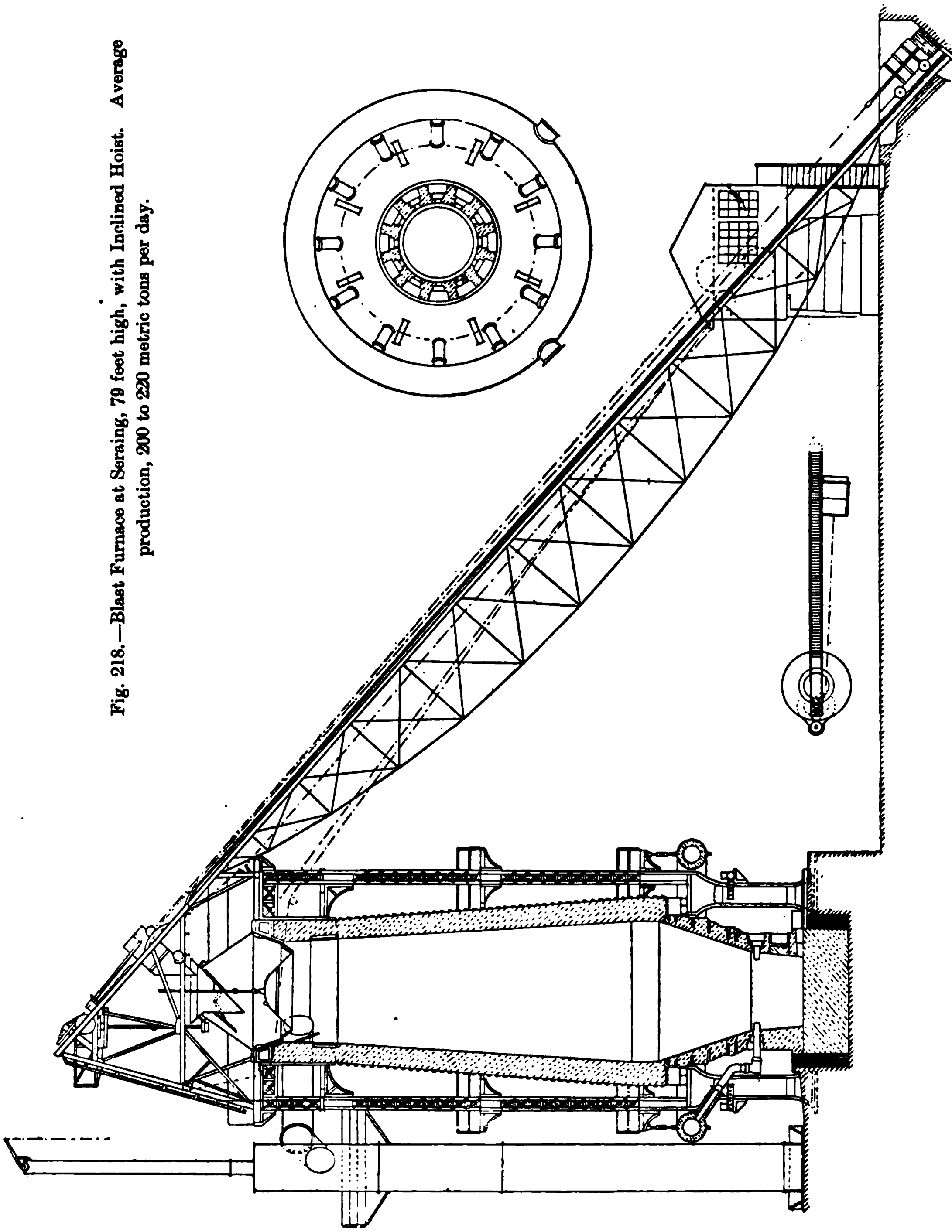

Fig. 218.—Blast Furnace at Seraing, 79 feet high, with Inclined Hoist. Average production, 200 to 220 metric tons per day.

bell, the open-topped type having fallen mostly into disuse. Compare with Fig. 218, which illustrates one of the furnaces at the Cockerill works at Seraing.

The *Throat*, or mouth, is closed with a bell, or cup and cone that prevents the escape of the gases, which are led away through pipes, and utilised for heating boilers, or driving gas engines. The throat is several feet less in diameter than the body of the furnace.

The *Body*, which is the preliminary heating area for fuel and ore, and has by far the largest proportion of furnace capacity. Generally the sides of this are straight, and tapered, enclosing a truncated cone, but sometimes they are curved or bellied. The amount of coning depends on the relation between the dimensions of the throat, the boshes, and the height.

The *Boshes* is the name given to the lower or melting area, and here much difference in practice exists, especially in the angle, which has to be ascertained for the best work. It ranges from 60° in the older Cleveland furnaces to 75° in many modern ones. The angle, the diameters at bottom and top, and depth are mutually related. At the bottom of the boshes the tuyere zone must be of moderate diameter, to permit the blast to penetrate to the centre of the materials, at the top a large area is required to give the solids as they descend to the hearth an exposure of several hours to the heated gases.

The *Crucible*. This is the smallest part of the furnace below the hearth, in which the metal collects, and above which the tuyeres enter. These point to the centre, and are generally arranged horizontally. These are water jacketed. In the Scotch tuyeres the water is circulated round a coil of pipes encasing the passage; in the Lloyd's, now more often used, water is sprayed into a jacket surrounding.

The intense heat of the blast furnaces burns out the lining of the boshes. Formerly less than 250,000 tons was obtained during the life of the lining, now there are cases of 1,000,000 tons having been exceeded. This is due to the use of water-cooled plates of cast iron, or copper, or bronze built into the walls horizontally. The plates are spaced at increased distances apart from above the tuyere belt to the upper part of the bosh. Water under pressure is brought in at the lowest row of plates whence it ascends in the series. *See* Fig. 219.

The furnace *Hearth* rests upon a foundation of brick-work built in clay or other material. Masonry built round this receives columns, to carry the body or stack, which is iron or steel plated, and lined with fire-brick.

The *Charge* of a blast furnace consists of ore, fuel, and flux (limestone), and the relative proportions of each vary with the quality of the ore. Coal, coke, and a mixture of each is used. Approximately a ton of coke and 2½ tons of ore are required for the production of a ton of pig, and about 30 cwt. of slag results. To melt this, a weight of air is required equal to about half the weight of the materials,—ore, limestone, and coke, and the waste gases comprise about two-thirds of the weight of pig and slag.

The solid materials take about seventy hours to pass from the top of the furnace to the hearth, during which period a gradual heating up occurs. About 75 per cent. of the calorific power theoretically available is utilised in the blast furnace. Blast pressure ranges from 3 to 20 lb. per square inch. The reactions which go on are the reduction of the metal from its ore in the presence of carbonic oxide. These have been treated very exhaustively by

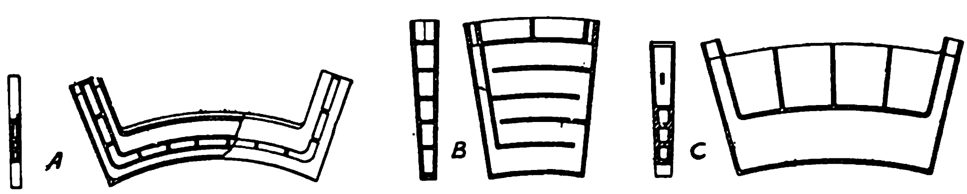

Fig. 219.—Water Cooled Blocks or Plates.

A. **Kennedy's two-pass water cooled bronze block.** *B.* **Cooling plate fitted with water baffles.**
C. **Gayley plate, used in Edgar Thomson furnaces.**

Lowthian Bell, and Dr Percy. Substantially they may be summed up in the words of the latter: "Temperature, carbonic oxide, and incandescent carbon explain all the phenomena of the blast furnace." The successive reactions are not so simple as they appear, because so many elements enter into the composition of ores, and fuels; besides carbon, there are phosphorus, silicon, alumina, and others, besides which there are differences in working.

Iron ore, in its descent, meeting the ascendant blast becomes hotter and hotter, passing through zones which are only approximately defined, in which warming up, reduction, carbonisation, and fusion occur, losing first its water, then its carbonic acid, then its oxygen. CO_2 is soon reduced to CO, and this at the high temperature reduces the metal by abstracting oxygen from the ore, the gas becoming again CO_2.

With regard to hard or easy driving; hard working wears the lining badly, and it requires a large hearth, and relatively small diameter of bosh, which is American practice. A large hearth is necessary to burn sufficient fuel, for which a large volume of high-pressure blast is necessary, and when this is combined with a bosh of small diameter, more oxygen is removed from the ores by the gases, and less by solid carbon. Hard driving ensures a more even quality of iron with less silicon than easy working. With regard to the more rapid wear of the lining it is held by those who adopt it, that more frequent relining is better economy than the long service working. The hard driving of the American furnaces may be judged from the following:—

An 80 feet high Edgar Thomson furnace, with a capacity of 18,200 cubic feet, receives 25,000 cubic feet of air per minute, through seven 6-inch tuyeres, at a pressure of 9½ lb. Over 10,000 tons of iron a month have been produced here. The Youngstown furnaces, 106½ feet high, with a capacity of 26,500 cubic feet, receive from 50,000 to 60,000 cubic feet of air per minute, through sixteen 6-inch tuyeres, at a pressure of 15 lb. Over 17,000 tons a month have been produced in these. At the Duquesne furnaces 793 tons of pig have been produced from one furnace in a day, or at the rate of over 5,000 tons in a week.

Blast Furnace Gas.—The great advantage of utilising blast furnace gas is that it does away with the steam boilers hitherto heated by such gas, and employs it direct for the driving of engines. At the Cockerill works it is estimated that while the boilers which are heated by the furnace gas supply steam for about 2,500 HP. the same if used in gas engines would provide about 12,000 HP. The difficulties which are met with in the utilisation of blast furnace gas are due less now to the presence of dust than to that of tar. The dust can be reduced to $\frac{1}{5}$ of a gramme per cubic metre, but the tar passes on and causes the valves and piston rings to stick, and it becomes deposited in the cylinder and passages. In most cases these engines are used in installations where sudden stoppages would derange the works, as for blowing, for electric lighting, and for mines, hence the necessity for purifying the gas beyond that necessary to prevent the cutting and scoring of working parts.

Blast Furnace Gas Engines.—Somewhere about the year 1893, Mr B. H. Thwaite was struck by the great similarity of producer gas and blast furnace gas, and, with a view to the employment of the latter for power purposes, he made use of a demonstration producer gas plant for the purpose of synthesising a gas of the same proportions as certain analyses of blast furnace gas, or B.F. gas as it is now often called. The synthesised gas, even with a high percentage of CO_2 was found to work perfectly in the gas engine. Thwaite then prepared plans of a cleaning plant, and ultimately, with the co-operation of James Riley of the Glasgow Iron Co., he established a small plant and gas engine for the lighting by electricity of the works at Wishaw. Thwaite had already published something of his work in the *Iron and Coal Trades Review*, which drew Continental attention to the great possibilities of B.F. gas. Unfortunately, however, the Continental engineers, who should have been better informed, repudiated Thwaite's insistence upon the necessity of cleaning the gas before using it in engines. It is hardly necessary to state that the attempts to use uncleaned gas failed, with the result of retarding progress.

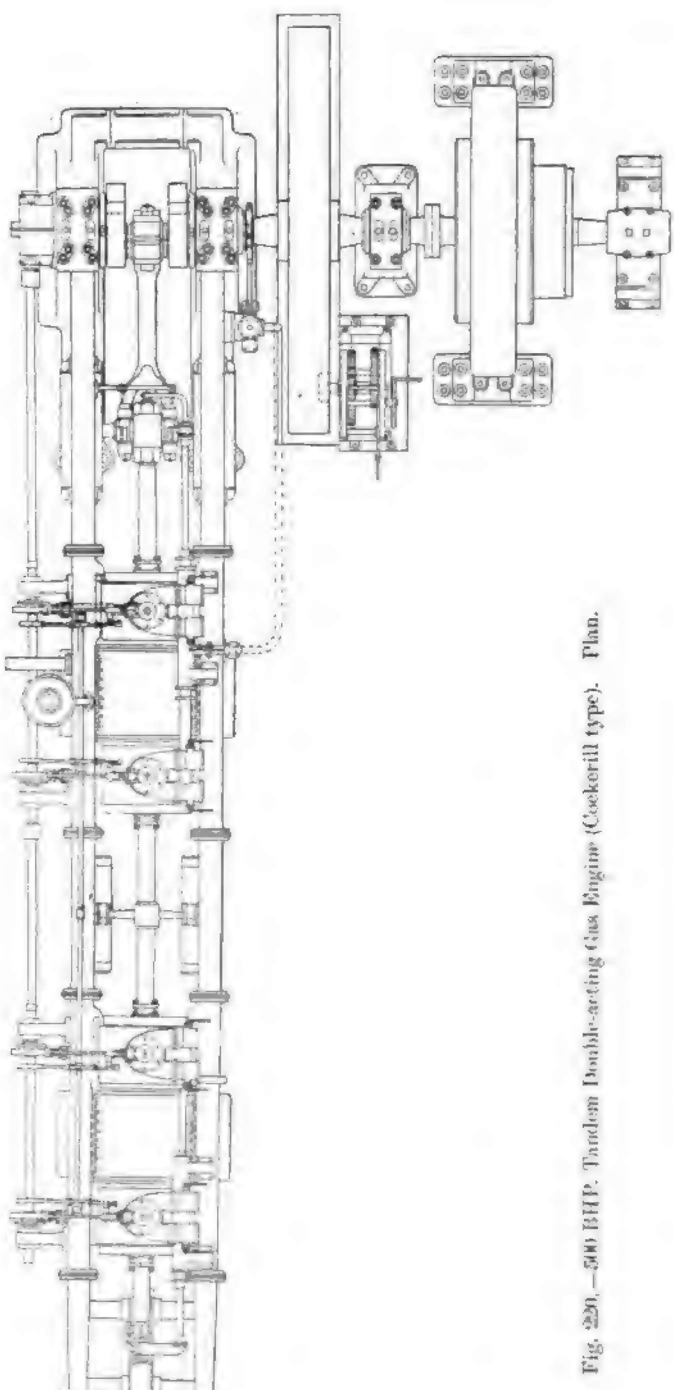

Fig. 220.—500 BHP. Tandem Double-acting Gas Engine (Cockerill type). Plan.

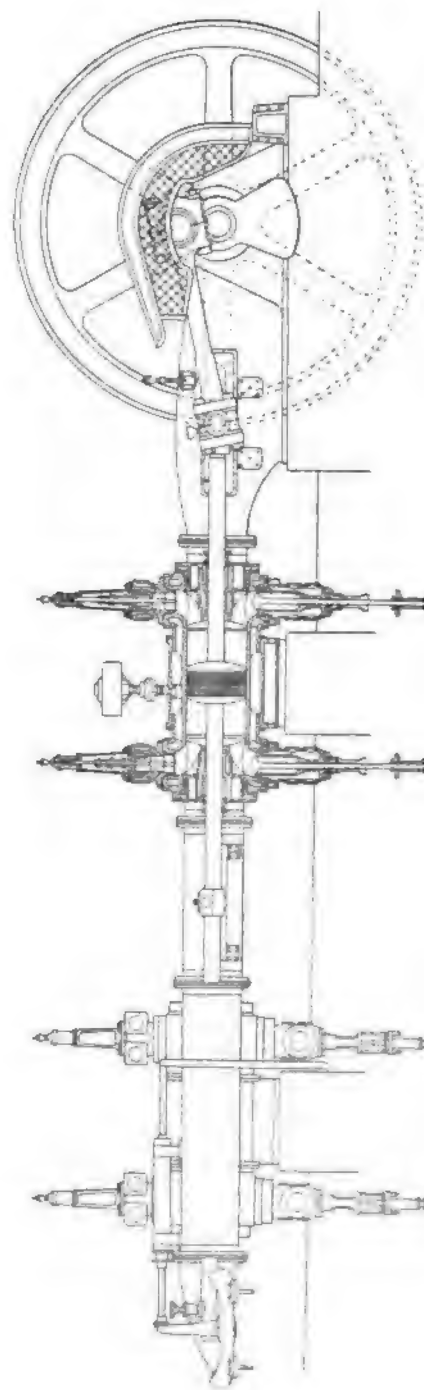

Fig. 221.—500 BHP. Gas Engine. Part Elevation and Section.

The Continental engineers, however, soon recognised the reasons of failure, and progress was afterwards rapid. Thus this English invention has made much greater progress on the Continent than it has done at home, and the great majority of large B.F. gas engines have had their rise in Belgium or Germany.

The first really large engine was one of about 650 HP. at the Paris Exhibition of 1900. It was of horizontal type, with a blowing cylinder in line with the working cylinder. This was made by the Cockerill Co. It was single acting, the piston was 4 ft. $3\frac{3}{16}$ in. diameter, with a stroke of 4 ft. $\frac{7}{8}$ in. It was designed to develop its power at 80 revolutions per minute, which, with an initial explosive pressure of from 310 to 325 lb. per square inch, produced a pressure of 300 tons on the piston at each explosion. In Germany, England, and America big engines were being simultaneously built to utilise blast furnace gas, and thus several distinct types have been developed. The single acting engine has given place generally to the double acting, and the design resembles less that of the old gas engines, and much more that of the steam engine in respect of general arrangement, but particularly of the valve gears. One of the big engines of this double acting type is of 1,200 HP. at 80 revolutions per minute, built by the Cockerill Co. for their own blast furnaces. The engine piston is 4 ft. $3\frac{3}{16}$ in. diameter, the blower piston is 7 ft. $4\frac{1}{2}$ in. diameter, and their stroke is 4 ft. $\frac{7}{8}$ in. It supplies air at a pressure of 23·6 in. of mercury.

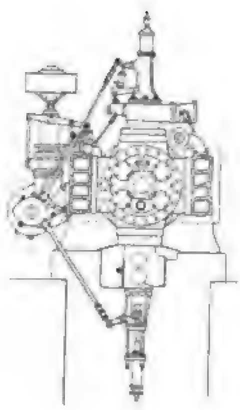

Fig. 222.—500 BHP. Gas Engine. End View.

Several of the Continental designs are being manufactured by British firms. A few may be described.

The 500 BHP. gas engine of Richardsons, Westgarth & Co., Ltd., Figs. 220-222, is of Cockerill type, and has two tandem horizontal $23\frac{5}{8} \times 31\frac{1}{2}$ in. cylinders, each of which is double acting, with piston rods, glands, crossheads, and guides, as in a steam engine. The gas and air valves are placed on the top of the cylinders, the exhaust valves below. The whole of each set of valves are thus worked by one cam on a long side shaft. The cylinder heads are removable. The cylinder body and ends, the stuffing boxes and the valve chambers are all thoroughly water jacketed.

The engine framing consists of two continuous girders extending from the crank pedestal to the extreme end of the engine, and the cylinders are attached by one end only to the frame and are thus free to expand or contract. The Otto cycle being worked to, there are therefore two impulses per revolution.

By means of a telescopic pipe and a pump water is circulated through the pistons and rods at a pressure of 40 lb. Compression is constant, and gas admission is controlled by the governor.

Magneto-ignition is used, and the engine is started from a compressed-air reservoir. When using B.F. gas, compression is kept high, and the consumption is about 95 cubic feet per BHP. hour. The same firm's 1,200 IHP. engine has four cylinders and two cranks. The two-cylinder engine has ordinarily a cyclic variation not over $\frac{1}{200}$, and can be used to drive alternators in parallel. An installation of large engines, by Richardsons, Westgarth & Co., Ltd., is also shown in Fig. 223, Plate XII.

Crossley Bros., Ltd., build a double-acting two-cylinder engine on steam-engine lines, the main cylinder casing being cast with the front end valve chambers, while the rear valve chambers are carried by a back end casting which is attached to the main casting by long bolts. The working liner of the cylinder is held between the fore end of the main casting and the back casting by these bolts. Full water cooling of cylinder, heads, stuffing boxes, pistons, and rods is arranged. Governing is by moderated charges except at very light loads when some explosions may be omitted.

The Körting gas engine is made by Mather & Platt. As much as 1,000 HP. is obtained from one cylinder in the large sizes. The engine is supplied with its explosive charge

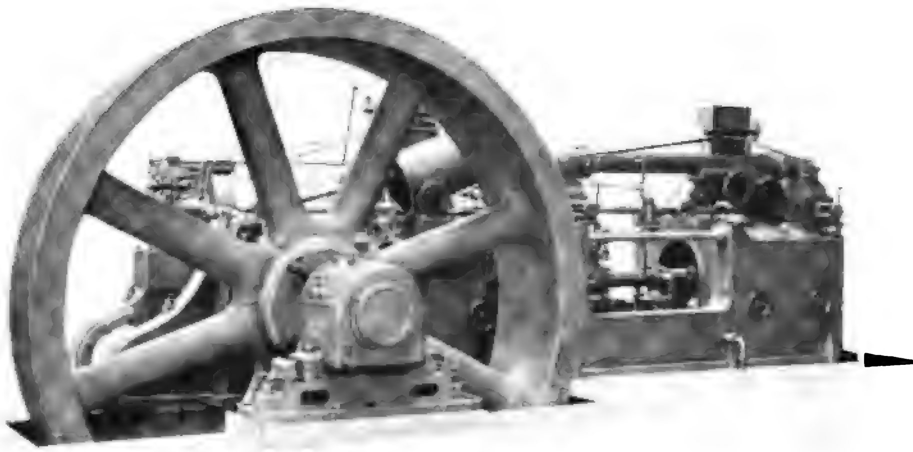

Fig. 224.—Blast Furnace Gas Engine, Type from 400 to 1,200 HP.
(The Premier Gas Engine Co., Ltd.)

Fig. 225.—Blowing Engine, 1,200 HP. (Premier Gas Engine Co., Ltd.)

To face page 204.

by separate pumps. It is double acting, with explosions every stroke at each end of the cylinder, the exhaust taking place at a ring of ports which are uncovered by a piston of great length. The new charge thus follows the old one. The first part of the new charge is pure air which scavenges out the last burnt charge, when the gas enters a little later and mixes with the air. The mixed charge is compressed on the return of the piston, and fired electrically at two points.

The air and gas pumps are placed on the same rod and parallel with the main cylinder, and are driven by a crank from the main shaft. The admission valves are above the cylinder, the air entering by an annular space round the gas entry. Full water cooling is provided to all parts, the water being led through the crosshead and piston rod to the piston, and thence by a pipe inside the piston rod and away by the opposite side of the crosshead. Governing is by moderated charges, and starting is effected by compressed air at 120 lb. The claims for this type of engine include the absence of an exhaust valve, the smaller cylinder, due to the two cycle arrangements, the scavenging and steady running.

To B. H. Thwaite is due the coupling of horizontal gas cylinders with vertical air-blowing tubes for blast furnace blowing. A description of this will be found under the head of **Blast Engines**.

In the engine of the Premier Gas Engine Co., Ltd., the cylinders, two in tandem, are single acting, and there is a scavenging cylinder or pump placed in an inclined position above one cylinder and driven off the connecting rod. Air at 3 lb. pressure is discharged into the two cylinders alternately, the ordinary valves of the working cylinders providing all that is necessary to distribute this scavenging charge. In a blowing engine with a 72-inch blowing tub the gas cylinders are 38 inches diameter, and the power is about 1,000 HP. The stroke is 4 feet, and the speed 75 to 85 revolutions per minute. The scavenging cylinder is omitted, the scavenging air coming from the blowing tub. Types of "Premier" engines are illustrated in Figs. 224 and 225, Plate XIII.

The analyses of gases given in the table below are culled from various sources.

Furnaces making ferro-manganese, spiegel, and basic pig usually produce more dusty gas than furnaces making foundry and Bessemer pig.

In certain tests by M. Greiner there were produced from two furnaces which turned out 300 tons of pig per day a weight of 13½ tons of heavy dust, or 10 grammes per cubic meter, and 3 tons of light dust, or 2·2 grammes per cubic meter.

GASES FROM COKE-FED FURNACES.

Volumetric Percentages.

	Lancashire.		Staffordshire.			Germany.
	I.	II.	I.	II.	III.	
CO_2 - - - -	8·78	4·0	5·76	6·19	6·11	6·86
CO - - - -	29·93	36·2	33·77	34·38	31·42	32·08
H - - - -	1·62	1·0	4·45	3·32	3·27	2·11
N - - - -	59·67	58·8	56·02	56·11	56·20	58·95
	100·00	100·00	100·00	100·00	100·00	100·00
Thermal value per cubic foot at 60° Fahr. B.Th.U. - - -	100·0	118·3	120·2	119·0	109·4	108·3

From 2 to 3 grammes of dust are often found in washed gas. Mr Keith of Middlesborough gives 2 to 5 tons of dust from a make of 600 to 700 tons of Cleveland iron, but another furnace gave scarcely 1 ton from a make of 600 tons. The blast weighs about 4·47 times the weight of coke used, and the effluent gases (neglecting steam) about 5·83 times the coke.

All processes of cleaning blast furnace gas are based on Thwaite's methods. The necessary operations are cooling to eliminate the steam, washing to take out the dust, and a final passage through a filter to eliminate the last few particles of finest dust. Among other things Thwaite has employed a fan to propel the gas, and the centrifugal action of this to throw the dust against the outer casing, a stream of water being admitted to flow through the fan and ensure washing away of the dust now thoroughly wetted. Thwaite lays particular stress on his box washer. He passes the gas first through a series of two box washers so arranged that the gas enters one of them and is partially purified and cooled. It then passes through the second washer which further purifies and cools it, and then it is suitable for introduction to the centrifugal fan on the blades of which jets or sprays of water are maintained. The fan is capable of drawing the gas if necessary through 20 inches head of water. The top of the washer box may be a water tank in which hard water is heated until it deposits its lime salts, and the water can then be used in the jackets of the gas engines, or soft water may be heated for steam purposes.

Partitions are fixed to distribute the flow of gas evenly, and hung from the partitions are perforated frames which can be agitated from outside the box. The draught of the fan sucks the gas through these perforated frames in fine streams or small bubbles, and an elongated seal permits the deposited dirt to be drawn from the box bottom. The water acts better as a cleanser when it becomes thickened by deposit, and the addition of some liquid tar is generally useful. Some tar oil may also be added with the water spray in the fan to prevent adhesion of the dust to the fan blades. From the fan the gas is forced through a solid resistance filter to a gasholder, and any excess of gas is allowed to escape back again to the suction side of the fan, the escape valve being operated by the action of the fully-filled holder.

The filter is of circular form, with filling of sawdust or shavings. The layers are circular in plan enclosing a space into which the gas enters after passing the 6-inch wall of filling. The sawdust is held by a wire netting, and a means is provided for agitating the sawdust to help it to shake off its collected dust. This agitation refers to the looser material in the central space of the filter, not to the more tightly packed annular 6-inch wall.

Only by thorough cleaning can B.F. gas be used in gas engines with satisfaction, but the cleaned gas is an ideal fuel. It contains little hydrogen, and will therefore admit of high compression without danger of pre-ignition, and it burns when ignited with sufficient slowness as to provide a time for the piston to travel away nearly or quite as fast as the volume of gas in the cylinder is increased by the combustion and added temperature. Thus the heat of combustion is directly converted to work, and efficiency attained.

Blast Furnace Hoist.—Early blast furnaces were charged by hand, by men who tipped the ore from wheelbarrows after it had been brought up an inclined way by a loaded truck, ascending while an empty one came down. Later, vertical lifts have been used freely, for which various motive agencies have been employed, hydraulic and pneumatic, and balanced lifts, besides direct acting steam hoists.

With the intense driving of furnaces now prevalent, the vertical lift is disappearing. The limitations are largely those of human endurance, and it is doubtful if more than about 1,500 tons of material can possibly be dealt with by this method in twenty-four hours, which is not adequate for present requirements. Hence the return to the inclined plane now so apparent, but in greatly improved forms. Skips or cars are now hoisted to the top of the furnace, and are discharged automatically. To these, when the locality is favourable, the long-armed Brown cranes become valuable adjuncts in the work of unloading vessels or cars, and conveying the ore to the place of storage. The rope

tramway is also used largely for the same purpose.

The four Duquesne furnaces of the Carnegie Steel Co. are served by a stock yard 1,085 feet long, about 226 feet wide, and having a capacity of 600,000 tons. It is spanned by three bridge cranes, and has an equipment of bins and cars for receiving and storing the ore. The supply to the furnaces is by the inclined modern skipway. The ore train, drawn by a small locomotive running on tracks between the ore bins has special cars, each of which carries a

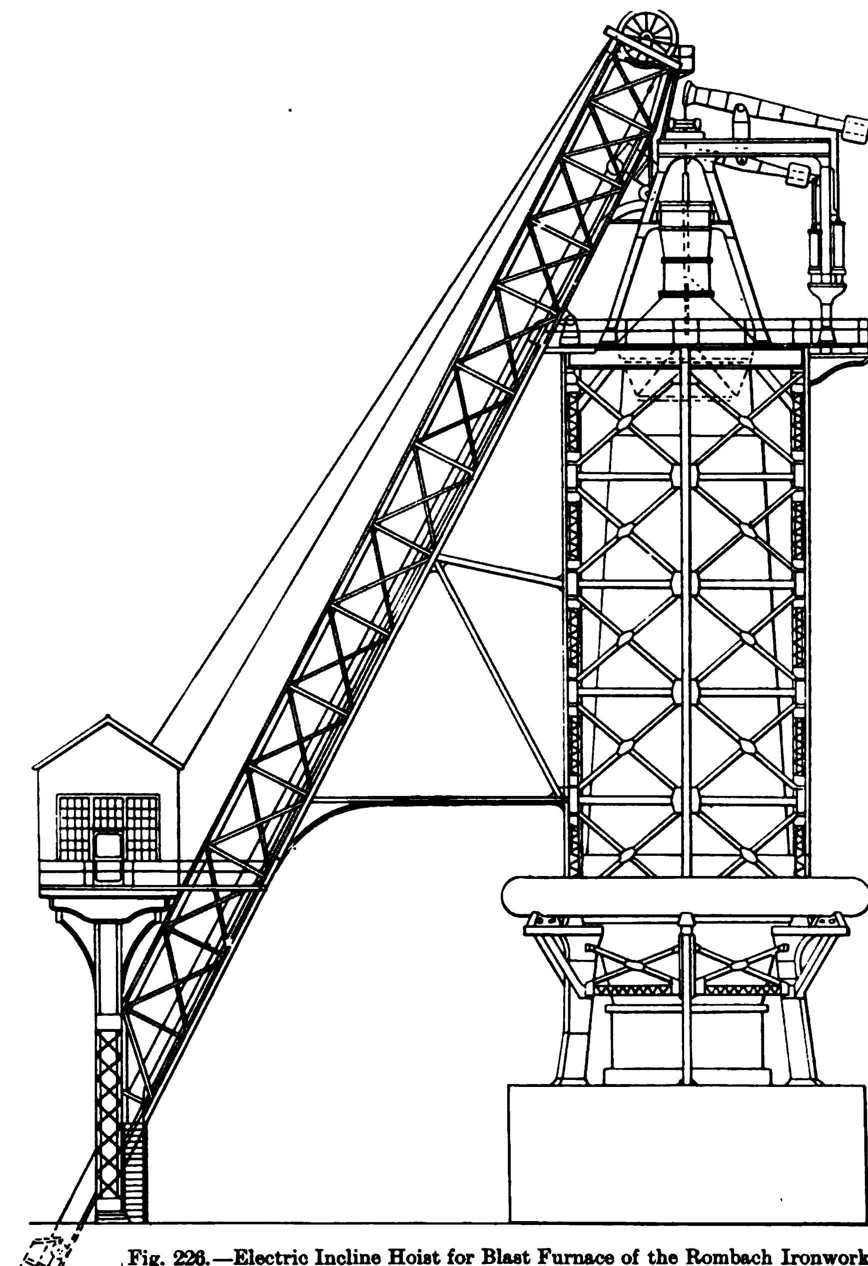

Fig. 226.—Electric Incline Hoist for Blast Furnace of the Rombach Ironworks, Rombach, Germany. (Wellman-Seaver-Morgan Co.)

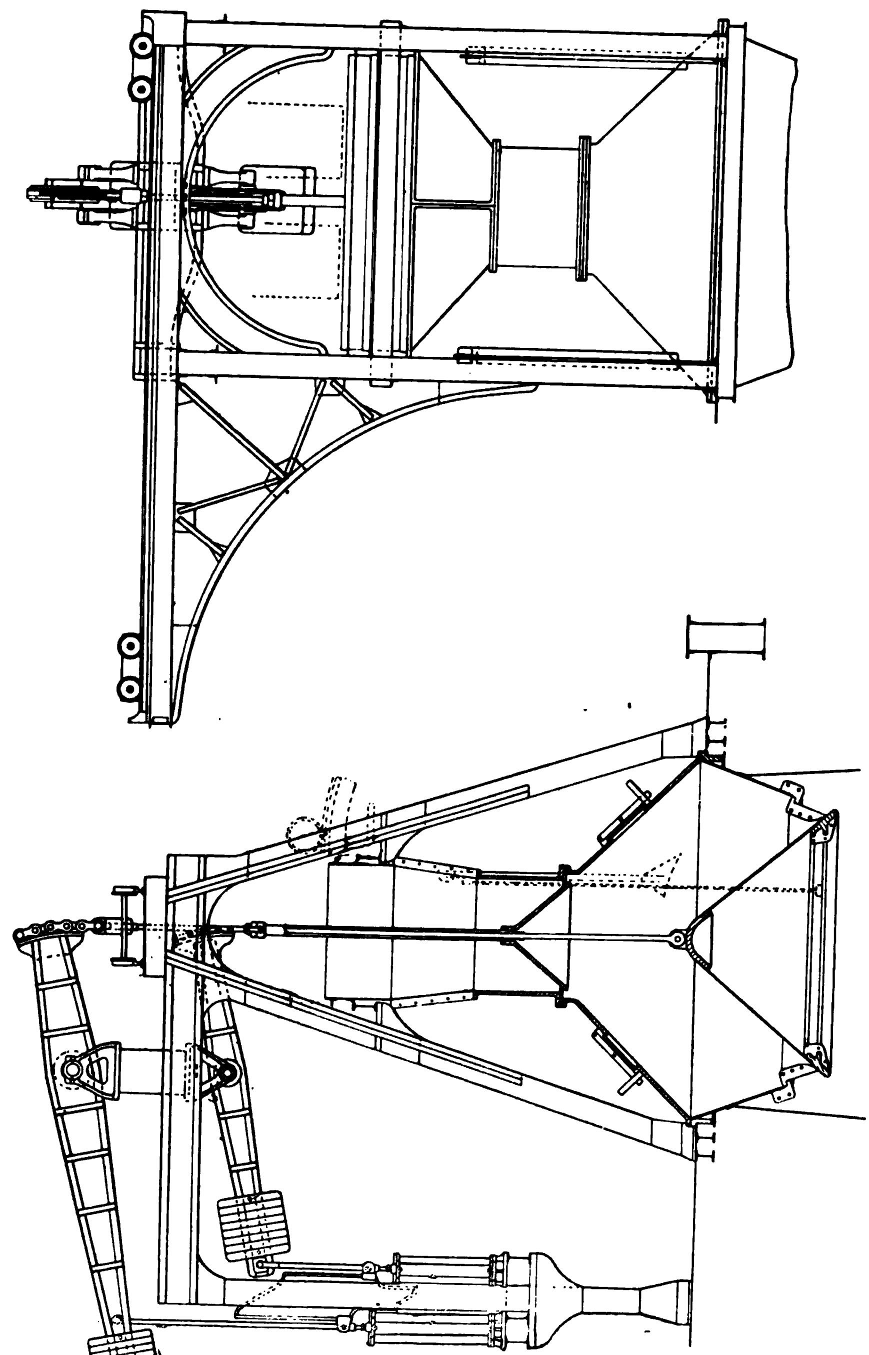

Fig. 227.—Detail of Bell Arrangements. (Wellman-Seaver-Morgan Co.)

charging scale on which the ore bucket rests, capable of carrying 10,000 lb. of ore. These buckets being brought under the incline are drawn up, and the contents discharged through the opening in the bottom of the bucket, which is done by lowering the bell through its attached rod and hook.

The bell device is the general method adopted, but its mechanism is varied in different plants. In most cases the object aimed at is to imitate the hand-filling process in regard to the distribution of the ore at any point around the periphery. Both steam power and electricity are used in these devices. Fig. 227 shows a very special bell arrangement made by the Wellman-Seaver-Morgan Co., and in use at the Youngstown furnaces. The skip, holding about 15,000 lb. of ore, is brought to the furnace top, where it is discharged into the supplementary hopper, the smaller upper one in the figure, the capacity of which is just equal to a skip load. The bell in the lower part of this hopper is then lowered by means of one of the cylinders seen to the left hand, the smaller one of the two in the figure actuating the counterweighted beam, to which it is seen connected, and to the opposite end of which the bell rod is connected. The ore is thus evenly distributed around the main furnace hopper below, which holds a charge of 30,000 lb., and this is operated by the larger cylinder to the left actuating the upper counterweighted beam, and through it the large bell rod which passes through the hollow rod of the smaller bell, and so distributes the ore. The upper bell is always closed while the lower one is discharging into the furnace, so preventing waste of gas; in this way hand filling is imitated with greater perfection of results.

Blast Furnace Slag.—The difficulties of getting rid of this slag are very great. From 10,000,000 to 12,000,000 tons are produced annually in the furnaces of Great Britain alone, and many schemes have been devised with a view to its utilisation. Sometimes land has been purchased, as in the Cleveland district, where nearly 4,000,000 tons are produced in a year, at prices ranging from £400 to £1,000 per acre, simply to dump the slag upon. Or it has been taken out to sea in hopper barges, both of which are costly for labour. As the old method of running slag into channels like pig and breaking it up by hand is not practicable with the increased output of blast furnaces, various mechanical devices have been introduced to lessen labour, such as casting the slag around iron hollow cores, carried on bogies; the contraction of the slag, in some cases assisted by sprays of cold water, causing the balls to crack and fall away into small pieces. Or blocks of slag are thrown on knife edges to break them up. Conveying machines and belts have been designed to carry the molten slag from the furnace to the place of shipment, trucks, or barges.

Slag has been utilised in many ways, but there are difficulties incidental to its employment, and the supply far exceeds the requirements. A breakwater has been erected on the south side of the Tees, of concrete, formed of Cleveland slag, and cement. Slag has been used to some extent for roadmaking, and for railway ballast, and for cement, but its principal utility is found in the production of slag wool, or silicate cotton. A jet of steam is made to strike upon the stream of molten slag as it issues from the blast furnace. The steam scatters it in the form of shot, and draws it out into fine tails or threads, which are sucked into a settling chamber by an induced current of air. A ton of molten slag yields $\frac{1}{4}$ cwt. of wool, which is used as a non-conductor for steam boilers, and pipes. Basic slag is used in Germany for manure.

Blasting.—The process by which solid and rigid matter is broken into a state of division that admits of displacement by hand, or filling by machinery, and which is now applied for the excavation and removal of rigid bodies in every branch of engineering practice. The process arose in the demands of mining for means of breaking out the rock faces of exploring passages in search of coal seams and metalliferous lodes, and of extracting the minerals; and the immense proportions which the coal and metalliferous mining industries have now attained, are very largely due to its agency. The results accomplished in mining suggested the application of blasting to other branches of engineering, and by increasing the charges of the agent, excavations increased in dimensions until the displacement

of huge and almost mountainous masses of rock became a practical operation. The conditions differed materially; the subterraneous excavation of minerals from the enclosing rock, no less than the forming of passage ways of limited area, was done in confined spaces with environment of enormous resistances; but the excavation of rock open to the universal atmosphere, with freedom of movement on two or more sides, presented a different problem, which increased in complexity with the magnitude of the work.

The primary question was whether the blasting agent, which in charges of 50 to 100 cubic inches, rapidly resolved into gases of dynamic energy adequate to detach the rock from its natural state, would, in charges increasing to several cubic yards capacity, develop the energy to produce a corresponding mechanical effect. The solution depended upon the homogeneousness of the blasting agent, and the rapidity with which ignition was transmitted from point to point throughout the charge. Blasting gunpowder easily satisfied both conditions; and excavation of huge masses of rock, at times approaching 300,000 tons, by charges of many tons of gunpowder, became a very valuable feature of excavation. This evolution in blasting was wrought by means of gunpowder, which is still the most valuable agent for useful effect; but in some special conditions, the modern detonating explosives admit of more rapid and effective application. During the last thirty years new explosives have been developed with different spheres of action, enlarging the field of operation, and providing blasting agents that can be applied to every engineering problem involving the displacement or division of rigid matter. The excavations in the construction of railways, docks, harbours, canals, and sub-aqueous foundations; and every class of subterraneous drivage, mining, quarrying and removal of huge masses of submerged rock in rivers and channels, can be carried out with expedition and economy by means of the blasting agents now available.

The principle of blasting is the rapid evolution of gases at an exalted temperature, developing pressures on the walls of the bore hole or chamber, ranging from 35 tons per square inch with common gunpowder, to over 100 tons per square inch by No. 1 dynamite, which rupture and displace the containing rock. Blasting agents divide into two classes, one exploding by combustion, as gunpowder, the other by detonation, as dynamite. Gunpowder develops its energy of rupture with a rapidity that allows expenditure in rending and splitting the rock to a considerable radius from the charge; dynamite develops its energy with lightning-like rapidity that pulverises the walls of bore hole or chamber, shattering or splitting the rock within a limited radius; and therefore yields a much less useful effect. These divergent effects are due partly to the rapidity of resolution into gases, and partly to the energy developed; explosion of gunpowder by combustion, and dynamite by detonation in similar conditions, indicate a much higher potential in the latter. This difference in potential, as determined in extended experience in practical work, may be expressed thus:—In ordinary blasting a hole that required 1 lb. of gunpowder would be charged with 6 to 8 ounces of dynamite. Considerable attention has been given to the development of an agent that would yield the potential of dynamite with the effective expenditure of gunpowder; *i.e.*, high energy with the pulverising and shattering action transmuted into rending and splitting effects. A large number of explosives have been introduced with this object, but until recently all developed the same intense local and limited action with only variation in degree. The agent recently discovered approaches very near to the border line between gunpowder and dynamite, and though exploded by detonation has no appreciable shattering action; the potential energy is expended in rending and splitting after the manner of gunpowder, and effecting not less area of rupture. This explosive was discovered at Ched, and with the addition of the usual suffix, was named "Cheddite"; it supplies the necessity of a blasting agent that develops the effective and economical expenditure of energy exhibited by gunpowder, but with a higher potential, and not affected by atmospheric conditions. In extensive practical blasting with good-sized charges, cheddite is found to develop a potential three times higher than gunpowder.

The nitro-glycerine, nitro-cotton, and nitrate

of ammonium detonating explosives have all done useful and effective work in different conditions, especially the first named; but their general adoption is restricted by two objections; the first and last are very sensitive to atmospheric conditions, and all three give shattering effects. The nitro-glycerine explosives solidify with crystallisation of the nitro-glycerine at a temperature of 42° to 44° Fahr., which obtains both in magazines and engineering work for many months in the year; and in this condition detonation occurs with slight frictional contact, causing numerous serious accidents; hot-water pans are now made compulsory to thaw the cartridges before they are used, which involves time, and sometimes other dangers arise. The nitrate of ammonium explosives liquefy on exposure to the ordinary atmosphere at all temperatures; they are necessarily packed in gas-tight cartridges, which do not admit of division for adjustment of the charge, therefore are not used in large excavations. The second objection applies to the three classes, which not only shatter the stone, but hurl it with projectile force for considerable distances; so that the machinery in the vicinity must be armoured, and all erections protected. The high impact they develop, also causes damage to buildings; and when they are used in sewer construction, the walls of houses over or adjacent to the sewer are often fractured or cracked. The nitro-glycerine explosives, gelatine and gelignite, are valuable agents in special circumstances, and especially in sub-aqueous work, as they are not affected by water; and their gelatinous form allows adjustment of charge as well as charging with rapidity, whatever the position of the hole.

There is no restriction in the use of explosives, except in certain coal mines defined as dangerous by virtue of yielding methane in quantity, and dry coal dust. In such mines only permitted explosives are used, *i.e.*, explosives that have passed a certain test fixed by H.M. Principal Secretary of State for the Home Department, and of standard composition. This test has secured a large development of gunpowder, nitro-glycerine, nitro-cotton, and nitrate of ammonium, explosives of which there are now nearly fifty on the permitted list, but in many cases by some sacrifice in dynamical value.

The largest quantity of blasting, as represented by the number of shots, is done in mining, and probably more than 20,000,000 are fired annually in the mines of the United Kingdom. These shots are charged with a few ounces varying to as many pounds of explosive; and fired either with safety fuse or by electricity; both methods are strongly advocated, but electrical ignition is increasing. The shot holes vary from 1 in. to 2 in. diameter, and from 2 ft. to 3½ ft. in length, in which the explosive is inserted attached to safety fuse or electrical wires, followed by strong stemming. The safety fuse usually burns at the rate of 2 ft. per minute, allowing adequate time for retreat to a place of safety; but in electrical ignition the charge can be fired at any moment that may be chosen. The important question of the quantity of explosive to use, is in its nature empirical. In ordinary blasting it is impossible to determine the resistances with exactness; and adjustment of the charge is largely dependent upon the estimate that can be formed from practical experience and observation. This measure is obtained with practical correctness; and though some shots prove to be overcharged owing to concealed and irregular jointing, as a rule the proper amount of explosive is used. The principal effect required in mining is rending, as distinct from shattering, and gunpowder either in ordinary or permitted form is most largely used. The detonating explosives with higher potential are adopted in stone where the crushing action is not objectionable: (they are not suitable for coal because their high impact shatters and reduces its value).

Quarrying occupies the second place in extent of blasting, and offers a wider field for operations, but is limited to certain blasting agents, *i.e.*, those effecting rending action. The stone, whether granite, basalt, limestone or sandstone, is required in the soundest possible state. When subjected to the shock caused by the high impact of detonating explosives and the internal stresses set up, the stone is damaged for monumental work; foundation beds that have to carry live loads, splinter; face work of buildings, suffers weathering; the nett yield of setts and paving

is reduced; the yield of the higher gauges of macadam from the stone breakers is less, with an increase of dust; and the waste in dust lime in the lime kilns is sensibly increased. Gunpowder, with its comparatively small impact, is therefore used for the principal work, though in special circumstances, gelignite proves a valuable adjunct. The excavation of the quarry face is done where possible by large blasts, and some computation is essential to determine the charge of explosive. This subject has been investigated by officers of the Royal Engineers for many years, in their work of demolishing fortifications. By means of exact drawings of the erections and their elevations, the lines of least resistance were worked out for determining the loci of the charges, which were estimated upon the cube of the resistances. The resistances of simple and compound masonry structures were calculated from known formulæ, and the ratio of the charge worked out on this basis. For simple masonry revetments, the charge of gunpowder was placed at $\frac{1}{10}$ of the cube of least resistance in feet, and proved adequate to reduce the fort to ruins. The ratio differs with the strength of the object to be removed, and the nature of the strata to be excavated. In blasting the chalk cliff at Seaford, the ratio adopted was $\frac{1}{28}$ of the cubed resistance; and the charges, amounting to 28 tons of gunpowder, were effective in displacing the mass; which, measured after the event, proved to be nearly 292,000 tons, or over 10 tons of chalk per lb. of gunpowder.

Another method used by the Royal Engineers was to base the charge upon the weight of rock to be displaced, and this was adopted in blasting a cliff in connection with the harbour works at Holyhead. The rock was extremely hard quartzose schist; and in the conditions there, the charges were fixed at 1 lb. of gunpowder per 3 tons of rock. The result of the blast was computed at $3\frac{1}{3}$ tons per lb. of explosive, but this low yield was evidently due to ineffective adjustment of the charges, as a few years later a similar blast yielded $7\frac{1}{2}$ tons of rock to the lb. factor. This method has no claim to exactness nor certainty; the blasting of huge masses of rock is a problem in which all the factors should be gauged as accurately as possible; concealed elements estimated, and the resistances to displacement calculated; in this way only can the operation be accomplished with any certainty, or without a large waste of explosive. An illustration is afforded by a blast at Yr Eifl Quarry, Carnarvonshire, some years ago, which yielded something between 14 and 20 tons of granite per lb. of gunpowder, showing that if the factor of three tons adopted at Holyhead, or even the later result of $7\frac{1}{2}$ tons, had been used here, there would have been an enormous waste of gunpowder.

In the limestone districts of Derbyshire, immense quantities of stone are obtained in large blasts by the usual method of tunnelling into the cliff, and forming chambers on opposite sides of the tunnel. The chambers are charged with gunpowder. On one occasion a nitroglycerine explosive was used, but developed its characteristic local action by forming funnel-shaped craters over the chambers, and leaving the mass otherwise undisturbed. The results have varied, and although the mass of rock was always more or less displaced, there has been room for considerable improvement, which could have been gained by applying exact methods for determining the charges. This precaution is the more necessary because the limestone is intersected with numerous divisional planes and fissure joints, sometimes concealed, which easily vitiate an empirical estimate made without regard for such contingencies. The excavation by tunnel and chambers also left room for economy in the condition of the rock as delivered by the blast, which involved considerable labour in handling. Another method is now adopted of terracing the rock with faces 25 feet deep, boring vertical holes on the top, chambering them by firing unstemmed charges of gunpowder, and then introducing the blasting charge. By this method a smaller extent of rock is blasted, but it is delivered to the floor in convenient-sized pieces that admit of more economical handling. The method has been developed to great advantage by the new explosive "cheddite"; and recently one such hole prepared for a charge of 400 lb. of gunpowder was charged with 120 lb. of cheddite, which rent the floor of the terrace for a length exceed-

ing 250 feet, and delivered over 1,600 tons of rock in condition for rapid handling and despatch; giving a useful effect of over 13 tons per lb. of explosive and economical delivery.

The above principles and methods of blasting are also applied in the other branches of engineering, for cuttings in railway, canal, and every enterprise involving excavation; and with such agents as gunpowder, cheddite, and gelignite, the scope of the steam navvy has been so largely extended, that even the intercalated beds of Clay and Lias Limestone can be removed by this machine, as was done recently in the construction of the London and South Wales Direct Railway.

Blast Main.—The main pipe which conveys blast to a furnace.

Blast Pipe.—Specifically the pipe which discharges the exhaust steam from the cylinders of locomotives into the chimney. *See* **Locomotive Engine.**

Blast Stove.—A **Hot Blast Stove.**

Blazed Pig.—An inferior grade of pig iron. It is highly silicious.

Blazing off.—A method of tempering used for springs, and many small articles in which the temperature is judged by the flashing or burning of a grease or fat.

Blechynden Boiler.—A water-tube boiler of the accelerated circulation type. It resembles the Yarrow boiler in its general build. The tubes are only very slightly curved, are inclined towards the vertical, and are expanded into thickened plates in two lower chambers, and one upper chamber or drum. There are no external downtakes, the water descending by two outside rows of tubes removed from the main sets of tubes. The tubes are withdrawn through the upper drum, by removing its upper portion.

Bleeding.—Red rust from underneath boiler scale, which denotes hidden corrosion.

Blind Holes.—*See* **Blank Holes.**

Blister Copper.—*See* **Copper.**

Blister Steel.—*See* **Cementation.**

Block.—A term which, used either alone or as an affix or prefix, denotes a large number of objects, the principal of which will be found under suitable heads, as **Pulley Blocks,** &c. Pieces by which the weight of a swing bridge is taken off the central point are blocks. Cubical masses of concrete are concrete blocks, and their moulds are block moulds, and the work is block work, to distinguish it from monolithic work. The block system relates to railway signalling; teeth used in moulding wheels by machine are tooth blocks. Blocking up, and blocking down denote various workshop processes. The snatch block of a crane is the lower lifting sheave with its entire fittings, a tail block denotes a fitting at the rear of a crane, and some other objects; a tuyere block is the back of a smith's hearth, &c.

Blocking Girders.—A device employed in portable balance cranes to afford artificial stability to them when lifting medium and maximum loads across the gauge. Though cranes are stable when lifting in line with the wheel base, comparatively few are built to be stable in all other positions, hence the reason for "blocking them up" between the angle of upset, and the position at right angles with the wheel base. The blocking girders provide a base about equal to that afforded by the centres of the running wheels.

In their simplest form these girders comprise two rolled I joists supported in straps suspended from the ends of the truck. When in use, timber blocking is wedged between the girders and the ground. At other times the girders are carried with the crane, standing out awkwardly. To obviate this, two joists are fitted side by side on some cranes, so that they can be slid in and out as required. When not in use their ends are flush with the truck sides. Another method which has been adopted, though rather expensive, is to hinge the girders on vertical pivots at the corners of the truck, so that they can lie close to the truck when not in service.

Blocking Screws.—Screws which either support blocking girders instead of wood chocks, or which are substituted for them. They are of coarse pitch, properly square threaded, carrying round-faced circular blocks to rest on the ground, and the screws are carried in bearings coming out from the sides of the crane truck.

Block Mould.—A large framed wooden box, the nearest resemblance to which is a massive foundry core box, used for making concrete

blocks in, Fig. 228. Its sides, ends, and bottom enclose a rectangle corresponding with the dimensions of the block to be moulded. It is framed of 3-in. or 4-in. deals, battened together to make up the depth. Cleats at the ends of the side members prevent the ends of the box from being pushed outwards by the mass of concrete, and a transverse bolt about midway in the length prevents the sides from being bulged outwardly. The sides are clamped against the ends by means of bolts, two at each end, which are long enough to allow the sides

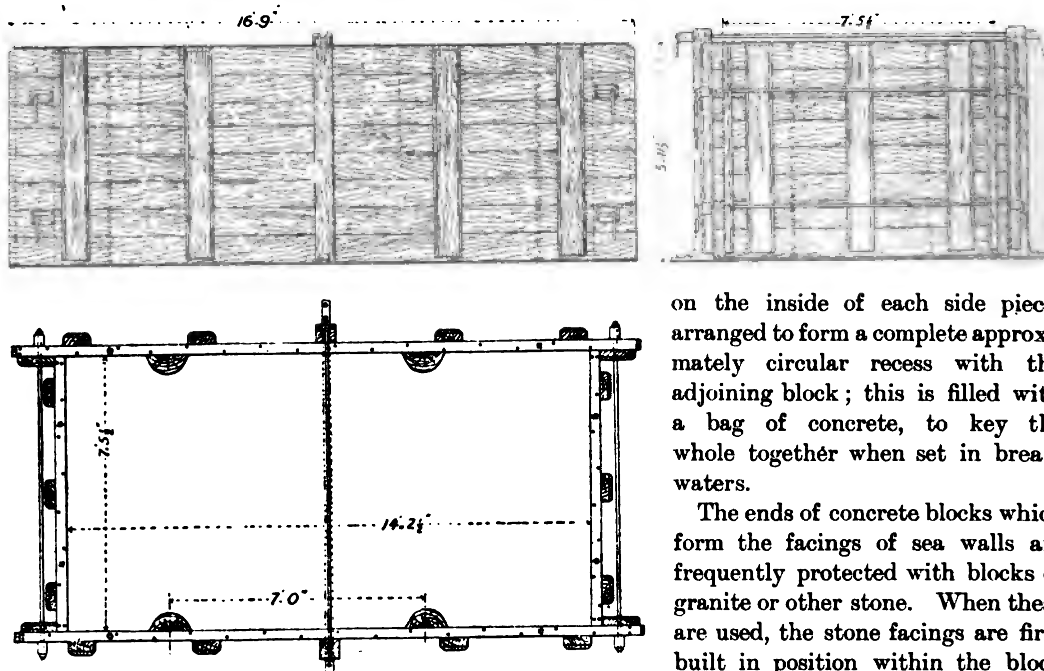

Fig. 228.—40-Ton Block Mould, Admiralty Harbour, Dover. (S. Pearson & Son, Ltd., Engineers.)

to be opened sufficiently to permit of the removal of the concrete block. The concrete is deposited in the box from a mixer or a skip above, to permit of which a line of rails is run along flanking the top of the moulds. Men in the moulds shovel the concrete into the corners, and distribute it properly over the area.

The interior of the box is seldom quite plain. As the blocks have to be lifted with lewis bars, holes are formed to receive these. Two tapered timbers (not shown), each of a section equal to that of the holes required, are fixed in the box at the angles suitable, and are secured at the top of the mould by a notched board (just as similar pieces are supported in a core box by means of a steady bar). These, which correspond with core prints, are drawn out before the concrete has set hard.

Besides this, provision has to be made for bonding or keying the concrete blocks after they are set in place. If above water, grout is poured in recesses formed in the sides of the blocks. Or recesses may be formed by fitting wood blocks of nearly semicircular section on the inside of each side piece, arranged to form a complete approximately circular recess with the adjoining block; this is filled with a bag of concrete, to key the whole together when set in breakwaters.

The ends of concrete blocks which form the facings of sea walls are frequently protected with blocks of granite or other stone. When these are used, the stone facings are first built in position within the block mould, and the concrete is shovelled against them. The outer faces are squared, but the inner ones are left rough and broken, and of different lengths, to afford a better hold for the concrete. After the concrete has set sufficiently, the box sides are unbolted, the sides and ends tilted outwards, and the block can be lifted with a Goliath or other crane and deposited in the block yard to harden thoroughly. *See also* **Block Work**.

Block Setting.—The setting of concrete blocks is effected either by a Block-setting Titan crane, or by a Goliath, or a Derrick. The blocks are suspended therefrom, and set by men making minute adjustments, and signal-

Fig. 229.—30 Tons Block Setting Crane. (Ransomes & Rapier, Ltd.)

Fig. 230.—Block Yard, Admiralty Works, Dover. (S. Pearson & Son, Ltd.)

To face page 214.

ling to the crane driver above. The work is done similarly below and above water, except that divers have to be employed in the first case. The blocks are lifted by lewis bars. Clips would be unsuitable as interfering with the making of the joints. The blocks are readily adjustable when just kept "floating" over the face below, and when set, the release of the strain on the chains drops the block on its bedding. Afterwards they are keyed by pouring grout into the recesses formed in their meeting faces.

Block setting can only be done in summer weather when the sea is comparatively calm. In some situations only about four months out of the twelve can be reckoned as available for this work, but the winter can be utilised in the preparation of the blocks.

Block - Setting Crane. — This class of crane, an example of which is shown by the photo, Fig. 229, Plate XIV., has been designed to meet the requirements of the concrete block system of harbour and breakwater construction, the development of which was mainly due to the late Sir John Coode. The term Titan is commonly applied to the type of crane which has been specialised for this work, but it now includes a large number of variations in design.

Speaking generally, and these remarks are of almost universal application, a crane of this type is required to deposit the concrete blocks many yards in advance of the front of the main framing which carries the jib. The exception occurs when a temporary staging is built out by means of derricks, on which Goliath cranes travel, setting blocks within the width of the staging. A great example of this kind occurs in the Dover Harbour extension, which is a departure from the usual practice. The Goliath in such cases is a Block setter, but not a Block-setting or Titan crane.

A Block-setting crane which builds on in front must also be capable of building sideways in order to give breadth to lay the rails on, and batter to the sides, or else another crane or cranes must be employed to supplement the work of the Titan. In such a case Derrick cranes have been used as "side setters." But most Titans are now made to slew, and thus set both straight forward and at the sides. The following is a brief account of the development of this class of crane.

The first example made in England was constructed to the design of the late Mr W. Parker for Karachi Harbour Works, about 1869. It comprised a tall truck running on flanged wheels, and carrying a rigid horizontal jib, lattice braced, on which a jenny or block carriage was racked to and fro over the areas of deposition. There was no slewing motion, but the longitudinal one only. This design has been retained only in a very few cases.

A Titan for Colombo (1877), without radial movements, nevertheless covered the side setting areas by cross traversing the lifting mechanism of the crane across gantries, which were fastened on the bottom framing at right angles to the longitudinal travel, and extended laterally over each side of the lower framing.

The next type which was developed was represented first by a Block-setting crane made for East London Harbour, interesting because it was the first example of a horizontal jib supported by tension rods. Another type, of which two examples were made, dates from 1881, for Port Alfred and East London respectively. Its jib was horizontal, supported by tie rods from a king post, and it would make a complete circle round the post.

The type of Block setter, having a jib supported with tension rods from a king post was embodied in the construction of the first Tynemouth Mammoth in 1881. This remark applies to the broad design, but not to the materials, or details of construction. The crane was framed of timber entirely, including the bottom framing, the jib, and king and queen posts, and to this the iron work was attached. It was a bold design for the time, and its capacity has as yet been exceeded but slightly. It was capable of lifting, as its maximum working load, 40 tons at a radius of 95 feet. It was also a revolving crane.

For several years the design of cantilever jib, self supporting, has divided favour with the jib supported by tension rods. About the finest example ever built of the first named is at Peterhead Harbour, but many others varying in power have been made in England, and on the Continent. Apparently this type possesses

advantages over the other in regard to the simplification of details. In a tension-rod supported jib, the rods have to be attached to a king post above, and to stirrup anchorages on the jib, in order to leave room beneath and between for the jenny and the hoisting ropes or chains to pass clear. The cantilever jib does away with all this. On the other hand, the jib of a tie-rod crane is a very simple and light affair by comparison with the self-supporting jib. But as the latter can be lattice braced and thus proportioned throughout to the strains upon it, the advantages on the whole lie with it.

Most Block setters now are made fully revolving. A good many have been built to revolve through a circle arc only just sufficient to cover side-setting requirements, but the work involved in providing for complete rotation does not add very much to the total cost, while the machine is rendered better adaptable, being able to pick up a block at the rear and slew it round to the front, instead of being dependent always upon the services of the **Block Trucks**.

A Block-setting Titan must be a balance crane. As it is also a portable crane, stability at all radii and in all relations of the jib and superstructure to the truck has to be provided for. This is not usually effected by the use of rail clips, or blocking girders, but by providing a wide gauge, a long wheel base to the truck, and a roller path of large diameter to the revolving jib. The ordinary standard gauge is useless. The width must be sufficient to allow of the laying down of standard tracks between the Titan tracks to run the concrete blocks underneath.

If a gauge is very wide, the roller path is generally of about the same diameter as the width of the truck. But if not, the path is carried out over the sides, bringing in any case the centre of gravity of the revolving mass within the base. The upper roller path is bolted to the lower face of a circular girder riveted to transverse girders under the jib girders, and identical in section and diameter with the circular girder and path on the truck. Angle brackets further stiffen the connection of the top roller path with the jib members. Between the faces of the paths, which are coned, steel live rollers run. To assist in counterbalancing the jib and its load, the jib members are prolonged behind the frames and all the heavy gearing, engines, and boiler are located there. Additional balance is often secured by suspending a water tank capable of holding several tons of feed water, and besides this some tons of **Kentledge** may be required. The result is that the crane is stable under all conditions at maximum load, or no load, and there is little surging of the jib if a sudden drop and release of the load occurs.

Slewing is done, and the entire crane is travelled bodily from gearing at the rear end of the jib. The first motion slewing shaft passes vertically down through the centre of the post. The travelling is done by pitch chain to sprockets on the axles of the truck wheels, or in some cases by means of bevel wheels. The hoisting and lowering were done by chains until about 1881, the Tynemouth crane being so operated, but soon after wire rope was adopted and is now generally employed. The drums are grooved for the chains or ropes.

The mechanical problems which are involved in the construction of Block-setting cranes are due largely to the movements of such enormous masses. A big crane will weigh anything between 200 and 300 tons, and when carrying a load of 30 or 40 tons hanging out from 40 to 50 feet beyond the front wheels, it is easy to understand how the enormous load on the rails may be a cause of trouble, as it has been in many cases. When a load is being taken, the front of the jib drops several inches, and if the crane was not carried on springs the stresses due to the lifting and travelling of the load would cause frequent fracture of the wheels, and bending of the rails. These mishaps often occurred in the early days, before makers began to put springs to the axle bearings. These are now fitted either of the volute, or the leaf form. Even with these aids it is necessary to distribute the load of the crane over from twelve to sixteen wheels.

The wheels are made of cast iron or steel, with rolled steel tyres, which are turned on the treads. Generally they have but one tread,

but for very heavy work they are commonly made double, with a mid flange. The axle bearings are bolted to the under faces of the bottom horizontal girders.

The roller race and the broad gauge both conduce to steadiness of movement with heavy loads. The race is often from 30 to 35 feet in diameter, and the rollers are pitched at small intervals, giving practically continuous contact. Some of the rollers are maintained in radial positions by tie rods from the centre piece, others in intermediate positions are simply confined by the roller rings. Rollers are generally of steel, and turned cone-shaped to run on turned paths. The latter are made of mild steel segments bolted to the main circular girder with turned bolts. They are turned in a face lathe if one big enough happens to be in the shop, but if not they are planed to the bevel in straight bars, and then bent to curvature round a templet block.

The question of driving through pitch chain, or shafts and gears arises. Shafts and gears are of course adopted for first motions, but the connection between these and the travelling wheels is alternative. All the early cranes had pitch chain. The objection to this is the stretching with service and the rather jerky motion which it imparts to the travel. On the other hand, bevel wheels have often fractured, due to the sudden and severe stresses to which they are subjected. Of late years this has been got over by affording better support to their shaft bearings in stiff brackets of special form tied together with ribbing, making in effect a solid casting.

The slewing or rotation of the crane is accomplished easily because the slewing ring is made about as large in diameter as the roller race. The ring is cast in segments and bolted to the lower circular girder.

The drums for chain, or wire rope being large, ranging from 4 ft. to 8 ft. in diameter, have their grooves cast spirally, though similar grooves in small drums are often cut in the lathe. The attachments for the rope are made in different ways to afford security, examples of which are given under **Crane Drum**.

The older methods of building Titan framings with plates have been largely modified in favour of bracing for the beams of the main framings and of the jib. This lessens the mass to be moved, and is in harmony with similar modifications going on in heavy crane design generally.

Many Block-setting cranes have special attachments to enable them to perform other functions beside that of block setting. They are employed for grabbing, as illustrated in Fig. 229, Plate XIV., for lowering diving bells, and for bag work.

Block System.—The early railways had no signals. Not until 1834 was the first attempt made to establish signals on the Liverpool and Manchester lines by the fixing of a lamp on the top of a post by means of a ladder. Hand lamps by night, and flags and hand signals by day, were used on the early lines, and were followed by fixed signals, and these by the Semaphore, introduced by Mr C. H. Gregory about 1841, but trains were not protected by distant signals until 1848. All the early arrangements were of the crudest character. Points and signals were worked independently of each other, and perhaps by different men, sometimes by the same individual, who had to run from point to signal. Many accidents occurred in consequence of signals being lowered when the points were set wrong.

To obviate this risk, Mr Saxby invented an ingenious piece of mechanism in 1856, by which the levers for working both points and signals were locked together in such a way that it would be impossible to operate one set of levers without simultaneously operating the other. But experience has shown that this arrangement alone does not ensure absolute safety, because a signalman may inadvertently alter points and signals, and send a train on, when the block instruments show that the line is not clear. Accidents from this cause have led to the practice of combining the block with the interlocking system, and so eliminating the last risk due to human fallibility.

In Saxby & Farmer's most perfected system of interlocking it is impossible unless by some rare mischance for an accident due to false signalling to occur. The man in charge of one signal box may blunder, but the one at the next box must blunder also ere an accident can occur, because the set of signals at one box is

interlocked with the set at the next. The points cannot be moved until the signal arms are set. The signalman cannot open a point crossing to a main line, and yet give an "all clear" signal to the main line. Each lever is a part of a key which unlocks some others. The normal condition of a signal is always danger, so that should an accident happen to the mechanism, the worst result is that the signals connected therewith will indicate danger.

Without these automatic interlocking arrangements human fallibility would be quite unable to cope with the vast traffic which is now carried on at our great termini and main line stations at all hours of the day and night.

The block system in conjunction with the interlocking of points and signals has rendered railway travelling safer than any other mode of transit. By this system when worked "absolutely" it is impossible for two trains to be on one and the same section of line at the same time, that is, the first train must have passed the block station ahead before a second train is allowed to leave the block station immediately preceding. The broad features of its working are as follows:—

At the termination of each separate section into which the line is divided, there is placed a signal box, provided with two electric bells, and four block telegraph instruments, one bell and two instruments for working the traffic in each direction. If we name consecutive signal boxes, A, B, C, &c., then on the approach of a train to A, the signalman who is in charge there must call the attention of B by bell, and movement of small semaphore arm; or, in the older instruments, by dial needle, and ask, "Is line clear?" B must not reply in the affirmative until he has repeated back the signal sent by A and received from A a confirmation that B has understood and repeated that signal correctly. Then B will lower the arm, or peg the needle to "line clear," and the train will be despatched from A to B. When the train has passed A, the signalman there must give the bell signal "Train entering section B," and the man at B must acknowledge the signal, and unpeg the needle. A must then give B "Train entering section B" in the proper arm, or dial signal, which B must acknowledge, and receive from A an intimation that his acknowledgment is correct. Then B must signal for "Train on line." Precisely the same set of signals has to be exchanged between B and C, and so on. Every bell signal consists of a definite number of beats of the bell, and each dial signal of a certain number of beats of the needle, to right or left, or both in combination. Arm movements are between horizontal and diagonal. The signals in the code are very numerous, to embrace all contingencies that are likely to arise. Whatever the distances asunder of the signal boxes, whether a few chains only, as in the crowded metropolitan lines, or three or four miles, as in the country, it is absolutely impossible under the block system that two trains should be upon the same section of line at the same instant.

In one of Saxby & Farmer's patents the passage of the train by the side of the signal box is made to deflect the short arm of a lever placed underneath a rail; the long arm of the lever then makes electrical contact with the telegraph instruments in the box, and takes off a lock, without whose removal the signalman would be unable to move the handles of the block instruments to signal "line clear."

Block Tin.—*See* **Tin.**

Block Truck.—A low truck, with a flat top, used for transporting blocks from the moulds to the stacking yards, and thence to the place where they have to be set. They are generally of standard 4 ft. 8½ in. gauge, fitted similarly to rolling stock. At the Dover Harbour works a number of old tender frames have been utilised as block trucks, the tanks being removed. Generally the truck line runs at a slight gradient from moulds to yard, and the trucks descending by gravity are pulled up by a hand brake on each. But the yard locomotive or a portable steam crane can be used on a level road to haul several trucks along at once, and this is a more satisfactory method.

Block Work.—The term given to that system of construction of piers, harbour walls, breakwaters, &c., in which massive cubical blocks of concrete are used instead of natural stone. The late Sir John Coode introduced and developed the practice, and it has been adopted,

among other works, at Karachi, Madras, Colombo, East London, Port Alfred, Douglas, Peterhead, Jersey, Vera Cruz, Leixoes, and Dover. Generally the blocks used do not exceed 40 tons in weight. Blocks of 20 and 30 tons are common.

Objections have been made to this system on the ground that it is costly, because it requires a big plant, and heavy hoisting, and setting machinery. But on extensive contracts it is a very satisfactory system. The plant required includes machinery for mixing the concrete, and this may range from mixers hand operated, to continuous mixers driven by power. They must either deliver the concrete into the **Block Moulds** direct, or, as in many plants, they pass it into skips, which then deposit it in the moulds. A large area of block yard is necessary to afford stacking room for a store of blocks during several months. This has to be covered with a Goliath crane, the best for the purpose, because it spans the area, and affords head room also. Sometimes the Titan is used for this work. As it would, in exposed situations, be idle through all the winter months and stormy seasons, there is advantage and economy in turning it into a block-stacking crane for the time being. But during the setting season the Goliath scores, since it brings the blocks along to the rear of the Titan, while the latter is engaged in its own proper work of deposition, and the Titan simply has to be run back far enough to pick the blocks off the trucks. The farther a pier, or breakwater, or harbour extends out to sea the greater is the economy, because these cranes travel very slowly, and much time is consumed in making their trips.

Fig. 230, Plate XIV., is an excellent illustration of the block yard at the Admiralty Harbour Works, Dover, including the cliff railway to the right, down which the materials are brought. They are prepared in the house to the right, and brought in trucks to the bridge that spans the yard. The materials are fed with water into concrete mixers, driven electrically, four of which are seen in the figure, which mix as they travel, the system designed by Mr A. H. Owles, M.Inst.C.E., the resident engineer. The concrete is then dropped into the moulds, seen in rows, and a drawing of which is shown in Fig. 228, p. 214. The Goliath crane seen in the distance is one of several for lifting the finished blocks.

As block work deals with submarine operations, both diving bells and divers are employed. The bells are used by men levelling the submarine beds for the blocks, the divers go down to set the blocks. The diving bells are large enough to accommodate several men seated, and they are lowered by the Titan or Goliath. In the preparation of a suitable bottom, grabs play a large part both in deepening and levelling. These are operated by the Goliath or the Titan.

Bloom. — Derived from the Anglo-Saxon *Bloma*, "metal, mass, lump," and it denoted in the first place the mass of malleable iron produced by the direct process in the ancient bloomeries, as the old furnaces were called. *Bloma Ferri* occurs several times in Domesday Book. The term bloom now has a wider scope than this. It denotes a specific mass of steel, or iron, smaller than an ingot, and larger than a billet. It is the puddled ball of the ironmaker, and a pile of iron ready to be rolled.

Bloomery Furnace.—An ancient form of furnace for the production of malleable iron direct from the ore, formerly much used, but now superseded in English practice, though used to a slight extent in the United States and Canada. It is only suitable for rich ores containing over 50 per cent. of metallic iron. Charcoal is the fuel used, and the ore is powdered. The furnaces are small, built in ranges, and hot blast is used. The character of the product varies in hardness or softness, and is better suited for fusion for the production of steel, than for malleable iron.

Blooming. — The shingling or squeezing down of puddled iron or steel ingots into blooms, slabs, or rough bars. It is effected in the iron works by various squeezers and hammers, and by **Puddling Rolls**, the latter producing puddled bars. In steel works the ingot is put between rolls, termed in America blooming rolls, but here **Cogging Rolls**, and the process is termed cogging.

Blooming Mill.—The mill in which the various squeezers, hammers, and rolls are

located for the production of puddled bars of malleable iron. It corresponds with the cogging mill of the steel works.

Blow. — The act of blowing air under pressure into blast, and cupola furnaces, and into Bessemer converters. *See also* **Blow Holes**.

Blower.— This is distinguished from the piston compressor or from the fan, the duties of both of which are similar, but different in degree from that of a blower. In a piston compressor the volume of air which can leak past the piston and valves is so small that when the air outlet is closed, there is no limit short of the strength of the machine, or the driving power, to which it cannot compress the air fed to it. In the fan, on the contrary, the pressure attained is due entirely to the centrifugal energy impressed on the air by the rotating blades or wheel, and when the outlet of a fan is closed, the work of driving it is less than when the outlet is open, because in the former case no energy of movement is being impressed on the air, which simply revolves with the fan wheel and only produces a frictional loss, whereas in the latter case energy is added to a constant stream of fresh particles.

In the blower we have a middle position filled. The blower, like the piston machine, propels air by taking it into a space the volume of which is reduced to a minimum. This varying space is produced by the intermeshing with each other of a pair of two-leaved runners revolving in a casing. Necessarily two such runners cannot be perfectly air-tight, but they are approximately tight or sufficiently so to render them capable of pushing forward the air at pressures considerably higher than can be reached by a fan.

In the blower known as Beale's Gas Exhauster, a cylindrical runner revolves inside a circular casing larger than itself. The runner bears against the side of the casing, and carries a flat slider which slides in a slot in the runner, and is kept against the surface of the casing by spring pressure. The crescent-shaped space between the runner and the casing is filled with gas behind the sliding piece, and is pushed out before the latter. A continuous propelling effect is approximately secured, but a steadier result is obtained where two exhausters are run on one shaft, the sliding pieces being 180° apart. A blower of this type is kept more easily and perfectly tight than the two-leaved runner type or Root's blower, but it is suited rather for low speeds, as in gas exhaustion.

The Root's blower is capable of running at a high speed, and will give large volumes of air for cupola blast. Examples are given in Figs. 231-233, Plate XV. The general form of the runners of a Root's blower is that of the figure 8 with a thick waist, see Fig. 234. They are actually a pair of two-teeth pinions, but will not drive each other. Therefore they are fixed upon parallel spindles which are made to run at equiangular velocities by a pair of equal-toothed wheels keyed to the spindles. This preserves the lobes of the blowers at the constant right-angled position relative to each other, and there must be a certain amount of sliding of the peripheral surfaces of the runners at such times as the larger radius of the one is in line with the shorter radius of the other. The peripheries at and near these points are not, in fact, pitch lines of contact, for they would not gear together if toothed and run at the equal angular velocity impressed upon them by the circular gear wheels keyed upon their respective spindles.

The outer casing or cylinder of the Root blower consists of a vessel with two semi-cylindrical ends united by straight lengths slightly longer than the radius of the curved ends.

The runners are so curved that when run, as they must be, at equal angular velocity, because of the gear wheels to which they are rigidly attached, they are in close touch with each other. Thus at each revolution of the machine, except for the space occupied by the runners, the volume of air discharged is equal to a cylinder of the radius of the two curved extremities of the casing, and a length equal to the breadth of the casing.

A novel form of the exhauster type of blower is the Hult engine if reversed in action, as it may easily be. In all rotary engines there has always been trouble with the rubbing of the sliding shutter piece upon the enclosing cylinder. In the Hult engine this rubbing is a minimum, for the cylinder also revolves with the internal runner, but on a centre slightly removed. There

Fig. 231.—ENGINE-DRIVEN BLOWER.
(Thwaites Bros., Ltd.)

Fig. 232.—BELT-DRIVEN BLOWER.
(Samuelson & Co., Ltd.)

Fig. 233.—MOTOR-DRIVEN BLOWER.
(Thwaites Bros., Ltd.)

Fig. 236.—BOAT PRESS.

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may be two or three sliding blades, which are kept against the cylinder by centrifugal pressure, and the internal runner drives the cylinder by contact as an internal friction gear. The peripheral speed of the inner rotor is thus the same as that of the inner surface of the cylinder, and the sliding pieces, which are carried round by the inner rotor, have merely a small differential sliding movement on the cylinder, thus greatly reducing the friction. The air or gas or steam must enter by the central spindle and make its exit also through this. This type of engine or blower appears therefore to be limited in size,' by reason of the rubbing friction of the central valve in the spindle. This friction partially compensates the friction abolished by the rotation of the cylinder. This limit, however, perhaps applies rather to the Hult machine as an engine, than to its possibilities as a blower, for in this use the inlet and outlet would perhaps permit of greater simplicity of detail.

The Root's blower is much employed for blowing cupolas and forge fires, and possesses this advantage over the centrifugal fan, that the air being positively propelled will enter the furnace against considerable resistance of ashes, &c.

The forms of the revolvers or impellers in the Root's blowers have been the subject of several modifications. The earlier ones, which remained in use for many years, had convex ends, Fig. 234, A, fitting in concavities of the same radius in the sides of the fellow revolver. When the journals wore badly the friction developed between these ends and sides became excessive, requiring much driving power to prevent sticking of the surfaces. The object in view in making such close contact was to prevent loss of air. Later forms are as shown in Fig. 234, B and C. The narrow edges there prove efficient in confining the air, and they also sweep out grit and dirt which may have got on the concave surfaces.

Baker's blowers have three revolvers of circular section. Two are slotted through their entire length to allow clearance for a pair of radial wings in the upper drum. These alternately sweep through the hollow portions of the two drums placed therewith. The casing is bored to prevent escape of air and to ensure smooth working.

Formerly many revolvers were covered with wood saturated with paraffin wax, but the wood being subject to the action of moisture and dry air gave much trouble, so that iron is now preferred.

In the manufacture of blowers much care has to be exercised. The casings have to be bored

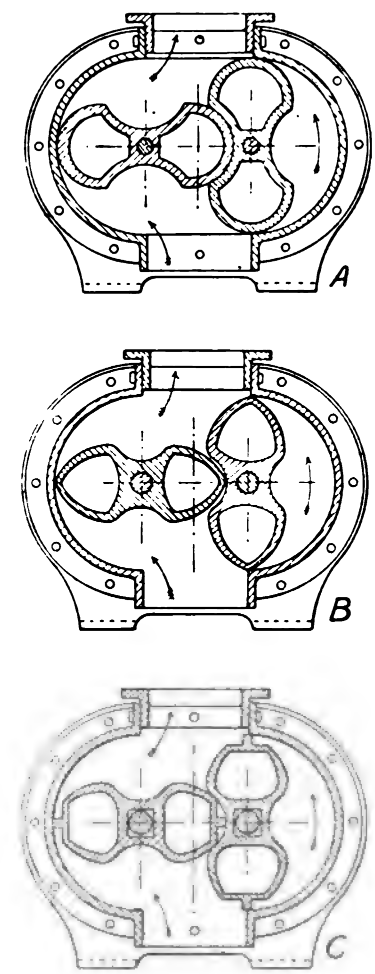

Fig. 234.—Evolution of Root's Blower.

and the surface of the revolvers tooled to fit the casing, and each other very exactly. When trouble arises it is generally due either to the wear of the shaft bearings or to the entrance of dust into the casing. The first is delayed as long as possible by giving good length, and by protection in covered-in boxes, and wire gauze lessens risk of the second.

Favourite types of blowers are those which are self contained with engine and casing on one bedplate, as in Fig. 231, Plate XV. The motion of each revolver is derived directly from its own connecting rod in the Root's blowers of this type, instead of one revolver being driven by gearing from the other, or separate driving belts being used.

The advantages of blowers over fans lie chiefly in the much lower rate of revolution of the former. As a blower running at 300 or 400 revolutions will do the work of a fan running at 3,000 or 4,000 revolutions, there is correspondingly less wear and tear. And this is in addition to the value of its positive, or exact pressure.

Blow Holes.—These are holes which occur either on the surfaces of castings, though as frequently beneath, and which breaking the continuity of the metal are dangerous elements of weakness. They are due to the entanglement of air and gases in the mould at the time of pouring, so that the metal is unable to occupy the same place, and fill up the mould. It is not the same thing as sponginess, though blow holes and general openness of grain frequently occur together in the same casting.

Blow holes are due to insufficient venting, so that all the air cannot escape, and to the presence of moisture. Either evil may be present in mould, or core. The remedy is ample venting, drying, dead-melting, and the use of risers or flow-off gates when necessary. Another preventive is to pour steadily, since air gets entangled with metal that is poured rapidly without first filling up the pouring basin.

Blow holes occur in all parts of castings, but more often on the upper parts than on the lower. They are often concealed by a thin film of metal that has flown over them, hence the need for hammer testing along upper surfaces where the presence of holes is suspected. Frequently their only indication is a minute hole or holes, which may be mistaken for mere sponginess. A bit of $\frac{1}{16}$-in. or $\frac{1}{8}$-in. wire thrust in, often reveals a blow hole of several inches in length.

Blow holes, even though few and of small size, should generally condemn the castings in which they occur, because they indicate unsoundness that may have extensive but invisible ramifications. This is especially so in castings subject to tensile or cross-bending stresses, more than in those under compression. A distinction should also be made between vital and non-vital parts. The fatal lugs of the first Tay Bridge will never be forgotten.

When possible the parts subject to severest stress, especially of the two kinds named above, should be cast lowermost, where blow holes are least likely to occur.

Blowing In.—The charging and lighting up of a blast furnace after its first lining, or relining. Old timber is first placed in the bottom—a ton or nearly in quantity, to a height of three or four feet, then several tons of coke, sufficient to fill the boshes, and over this successive charges of ore, limestone, and coke. When about one-third of the furnace is filled, the wood is lit, and the mass allowed to become warmed up, subsequently to which it is gradually filled. The blast is then turned on in partial volume only. The burdens are light, and the blast volume is regulated by changing smaller for larger tuyeres gradually for a period of from four to five weeks, at the end of which period the furnace is ready for the regular charging and full blast.

Blowing Off.—Discharging a portion of the water of a boiler periodically, from once to half a dozen times in a week with a view to getting rid of sediment, before it has time to become hardened and deposited on the plates. Blowing-off should be done when the water is quiet after a period of cessation of working.

Blowing Out.—The stopping of a blast furnace, only done when it requires relining, or when trade is slackening and unremunerative. It is done gradually, the burden being first reduced, the tubes and fittings removed, the throat charging discontinued, and the furnace allowed to run down, the last metal being tapped from the lowest possible point of the hearth.

Blow-off Bend.—A bend in cast iron or stamped steel bolted underneath the front end of a Cornish or Lancashire boiler to receive the flange of the blow-off cock.

Blow-off Cock.—The cock at the lower

front end of a horizontal boiler, or near the bottom of a vertical, through which the water and the solid matters which it holds in suspension are periodically blown out. Cases of fracture and leakage of blow-off cocks have occurred in consequence of their having been bound fast in the brick-work seating.

Blue Billy or **Purple Ore.**—Used as a lining for puddling furnaces. It is composed chiefly of ferric oxide, to the extent of 95 or 96 per cent. It is the residue obtained from the treatment of copper pyrites by the wet process, and from iron pyrites in the manufacture of sulphuric acid. It must not contain much copper, nor more than a trace of sulphur.

Blue Heat.—The temperature at which it is dangerous to do work on iron and steel.

Blueing. — Light iron and steel articles are blued to protect them from rusting readily, as well as for appearance. The articles may be treated in an iron pan filled with sand, powdered charcoal, or mahogany sawdust, or brass filings, and when heated to a dull red the articles are passed through it. They must be first polished, and freed from grease by rubbing them with powdered quicklime. If a piece of polished work is touched with the hand the mark will show after it is blued.

Another way is to boil the articles in a solution as follows:—4 oz. of hyposulphite of soda, dissolved in $1\frac{1}{2}$ pint of water, to which is added a solution of 1 oz. of acetate of lead in 1 oz. of water.

Another method is to coat with linseed oil, cover with hard wood ashes, and place in a furnace until the blue colour appears. The ashes are then brushed off, and the articles placed in a wire basket and immersed in sperm oil, and then washed in a solution of soda to remove the oil.

Steel may be blued by merely subjecting it to a temperature of from 500° to 600° Fahr. The blueing is the result of oxidation.

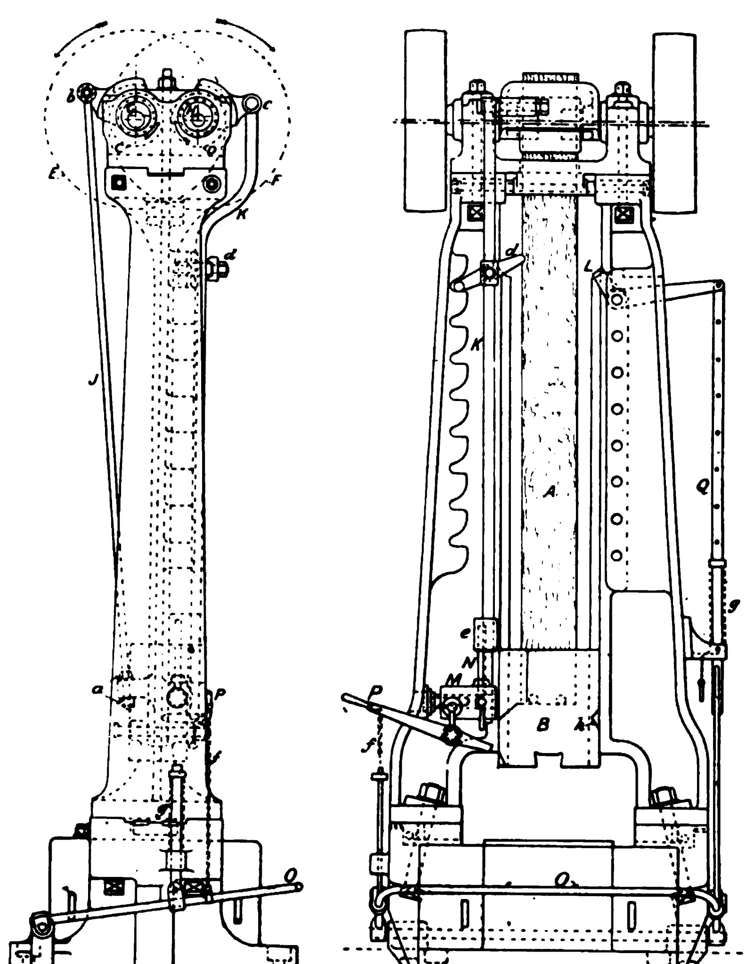

Fig. 235.—Board Drop Hammer.

More elaborate methods are adopted in blueing gun barrels, too lengthy for insertion here.

Blue Print.—*See* **Photo Prints.**

Blunt File.—*See* **Files.**

Board.—A piece of sawn timber that lies

between quartering and battens, and plank or balk. It may be of any width exceeding 5 or 6 inches, and any thickness below 2½ or 3 inches. The term also signifies a bottom board, or follow board, or joint board, or match board, or turn-over board.

Board Drop Hammer.—A type of drop hammer in which the tup is attached to and actuated by a board, alternative to that of a belt. *See* **Belt Drop Hammer**. Fig. 235 shows a modern type by B. & S. Massey. The board A is fitted in a slot cast in the tup B and secured therein with bolts. It is gripped and released by the rollers C and D, driven by the right and left hand pulleys E and F respectively through the two eccentrics G and H on the same shaft. D takes the principal part in gripping the surface of the board, E has a share, but its principal function is in compensating for the wear of the board, which adjustment is effected from below by means of the nuts *a* on the rod J, the upper end of which is attached to the eccentric lug *b* connected to G. The other vertical rod K connected by the lug *c* to the eccentric H regulates the operation of the tup. *d* is a dog which can be adjusted to any height on K to suit the length of drop required, and which carries the tripper lever seen, that is struck by a sloping edge on the tup. It is important to set this dog so that the tup shall fall through the shortest distance possible, or not more than 1¼ inch before the tup rests on the supporting catch L that is at the top of its stroke. If this is exceeded there is a risk of the fall of the tup causing fracture of the standard.

The method of effecting this adjustment is through the slide block M which is made to spring horizontally underneath the adjustable stop pin N for length, in a lug *e* attached to the rod K. The block M is struck from its normal position as held by the spring pin, by an inclined edge at the bottom of the tup, so that the rod N either rests on the surface of the slide block M, or drops through a hole in it. When the rod N is supported, the roller D is clear of the board A and the tup falls until it strikes the block M, pushing it along, and allowing the pin N to drop through the hole in M, which brings the rollers C and D into contact with the board, lifting it.

The hammer is operated by foot or hand levers, O and P respectively, and the two are connected with the chain *f*, while *g* is a spring which lifts the lever on the release of the hand or foot. The foot lever is connected with the rod Q and catch L, retained by the spring *g* to hold the tup in the notch until pulled down and out by pressure on either one of the levers. As long therefore as either lever is being pressed down the tup continues to rise and fall. If the lever is released then when the tup rises it remains at the top held by the catch L and so stays until released by the lever.

Board of Trade Unit, or **B.T.U.**—This is a unit of energy equal to 1,000 ampere-volt-hours, hence termed the kilowatt hour. The formula stands

$$\frac{\text{C.E.T.}}{1{,}000} = \text{B.T.U.}$$

Where C is the current in amperes, E the electromotive force in volts, and T the time in hours. The term kilowatt relates to the HP., which as its name implies is 1,000 watts, or the power expended by 1,000 amperes at a potential difference of 1 volt. 746 watts = IEHP.

Boat Press.—A press designed for producing boats of seamless steel, which has been in operation for several years at the works of the Seamless Steel Boat Co., Ltd., Wakefield. Originally the Heslop patent provided for stamping a boat from a single sheet, but this was found impracticable on account of puckering. All boats are therefore pressed in two pieces, and afterwards jointed along the keel. This has an advantage in permitting of the insertion of a stiff keel of bulb T section bent to the proper curves, and to which the flanged edges of the pressed sheets are riveted.

The advantage of a steel hull is that it is unaffected by heat as timber is, and that a blow will only bruise without fracturing it. The steel used is ⅛ inch thick. It is pressed hot, and necessarily quickly. The furnace is ranged in line with the dies. The lower die is lifted by hydraulic pressure as soon as one side of the sheet has been rapidly cottered to it by men stationed there for the purpose. The dies are bolted together in cast sections. They range up to 35 and 43 feet in length. The illustration, Fig. 236, Plate XV., is of a press 33 ft. by 12

ft., and 350 boats were pressed on this in 1904. The hydraulic pressure used is 800 lb. to the square inch. The boat fittings are of timber.

Body.—Used commonly to distinguish a main portion from the subsidiary ones. A carriage or wagon body is so termed, apart from its wheels; the body of a cylinder or pump distinct from its branches; the body of a paint apart from its colouring matters; the body of a swept-up core is its principal mass, apart from the finishing coat, &c.

Body Core.—A main, or principal core.

Body Flange.—A flange that fits anywhere on the body of a pipe or column pattern, and which becomes a guide for stopping off by.

Bogie.—This device was patented in 1812 by William Chapman, an engineer in the North of England, it was used on the Newcastle quays, and nicknamed "bogie" by the pit men, a term which has stuck to it ever since. Mr Robert Stephenson recommended a Commission of American Engineers who visited Newcastle in 1828 to adopt the truck for some curves of 400 feet radius in the States. A bogie engine was made in 1833 by Carmichael of Dundee. The locomotive had vertical cylinders connected by crossheads and side links to bell crank levers, which were connected to the driving wheels with rods. The trailing end of the engine was carried on a four-wheeled bogie. Not much was done in this way for several years, but the necessity for flexible self-adjusting axles arose as engines and carriages increased in length. In 1846 engines on the South Devon line were fitted with it. The early development of the bogie took place in America, locomotives being so fitted in 1832. In 1853 it was adopted on the large passenger engines of the Bristol and Exeter railways, for the Great North of Scotland lines, and on engines for some foreign railways. In 1857 came the Bissel truck which created a revolution in the older method. In this the entire bogie framing is pivoted, not between the axles, but at a point outside the driving axle, with the result that the bogie framing sways to right or left under the engine, and the axles are free to take up positions nearly radial to the curve.

Another good design is the Adams' bogie. A pivot casting at the centre is bolted to a stay between the main frames and is therefore rigidly connected to the main frames of the engine. The pivot fits in a hole in a casting which rests upon the bogie framing, which casting slides laterally in guides fitted between the bogie frames, having a lateral freedom of movement of from $1\frac{1}{2}$ in. to 2 in., and which is cushioned laterally by spiral springs on each side, the normal action of which is to maintain the engine framing centrally on the bogie. There are other systems, and numerous modifications occur in the practice of different lines. *See also* **Radial Axle Box**.

Boiled Oil.—Used for brushing over castings and forgings, before inspection, and painting, as a protection from rust, while its transparency leaves the castings open to inspection.

Boiler.—A term which covers numerous meanings under this and other names, as coppers, digesters, kiers, pans, stills, tanks, &c.

Boiler Efficiency.—The efficiency of a steam boiler is threefold, if by this is understood not only the boiler, but also its furnace and the operations connected therewith, thus including the boiler throughout.

The first operation is the combustion of coal or other fuel. Every fuel has its own calorific value, the whole of which it is possible to secure by perfect combustion. There are three combustible elements in most fuels, carbon, hydrogen, and sulphur. When these are perfectly consumed their products are CO_2 or carbonic acid, H_2O or water, and SO_2 or sulphur dioxide. Where combustion is imperfect any of these three elements may appear free in the final effluents from the furnace, or they may appear partially satisfied with oxygen in the case of carbon: they may appear in combination with each other. Thus carbon may appear as CO, or as C_nHxn or CS_2, hydrogen as C_nHxn or as H_2S.

The combinations of carbon and hydrogen are powerfully calorific, and their presence in the waste gas as free carbon or free hydrogen implies loss of efficiency. Carbonic oxide or CO in process of formation only generates 4,415 thermal units. Completely burned it produces 14,647 units, showing therefore a loss of two-thirds its calorific power by imperfect combustion. By introducing an excess of air it is usually

possible to burn fuel with a high efficiency of conversion, but it must be noted that the products of combustion being at a lower temperature may cause subsequent processes of heat transference to be less efficiently performed. The relation of the heat generated, to the heat contained in the fuel is the measure of the efficiency of combustion. But since temperature is an important factor, mere perfection of combustion is not to be sought to the exclusion of other valuable factors. Thus if a given weight of air should be sufficient chemically to satisfy an unit weight of fuel, and double this weight of air is actually used, then the efficiency of the process may very well be stated at only 50 per cent., for the duty of a furnace is not merely to produce heat in quantity but in quality. There must be the quality of high temperature, for it is only necessary to use very excessive amounts of air in order that the temperature of the products of combustion shall be lower than the temperature of steam at the pressure intended to be carried by the boiler. Therefore it is possible to reduce the efficiency of heat production and increase the efficiency of temperature production in order to secure a better overall efficiency in some cases. In other cases it is possible to reduce the efficiency both of heat production and of temperature production with better overall efficiency. The endeavour must always be to secure both a maximum of heat and of temperature.

Having produced the heat it now remains to transfer it to the water in the boiler. Since a steam boiler is always wanted to carry a given pressure, every part of the boiler must be at least as hot as the temperature of steam corresponding to that pressure. The furnace products cannot possibly flow away less hot than this minimum temperature. The heat-absorbing surfaces of a boiler have for duty the reduction of the temperature of the gases to a minimum. There are two of these minima. The one is the atmospheric temperature at which the fuel, and the air to burn it, commenced. With perfect combustion efficiency, and a final temperature equal to the atmospheric, the overall efficiency thus far would be 100 per cent. Such is impossible. There cannot possibly be a final temperature less than that of the steam. The maximum possible efficiency of boiler-heating surface is therefore represented by $\frac{H-h}{H}=E$, where H is the total heat generated, and h is the heat in the waste gases. If t is the boiler temperature and T the waste-gas temperature, and $t=T$, the nominal efficiency E would really represent 100 per cent., though $\frac{H-h}{H}$ might only be 80 or 90; for if $T=t$ the boiler has absorbed all the heat offered to it above the temperature t.

Actually the waste temperature T always is much above the temperature t, and the true efficiency of the heating surface of the boiler is the percentage of the heat which is taken up that it is possible theoretically to take up. This heat is $H-h_1$ where h_1 is the heat in the waste gases at the temperature t. If now the heat in the waste gases at the temperature T be called h_2 the true heating surface efficiency will be $E_1=\frac{H-h_1}{H-h_2}$. Since the transfer of heat through metal plates is more efficiently performed when the head of temperature is large, it follows that the value of h_1 and of h_2 will approximate more closely as the combustion efficiency is high, and also the process efficiency, by which is meant the relation of the temperature of the gases, assuming an adiabatic combustion, and the theoretical temperature on the basis of minimum air supply.

After the boiler has absorbed its heat from the furnace it remains to use it in steam production. The amount of heat not utilised is lost by radiation from the boiler surfaces. Heat has also been lost by radiation from the surfaces of the boiler seatings.

Of the calorific value of the coal a part has been lost by imperfect combustion, or rather has not been developed, part has been thrown away with the waste gases, and part lost by radiation. The ratio of the total heat put into the steam above the feed-water temperature to the total heat value of the coal is usually termed the overall boiler efficiency. It is, however, again hardly sound to state efficiency in these terms, since it is not possible to utilise any of the heat below the temperature of the steam

pressure. The true overall efficiency might more properly be stated as the ratio of the heat added to the feed water from its entrance to the boiler, to the heat value of the fuel stated above the temperature of the pressure on the basis of a combustion with a minimum chemical weight of air. To illustrate, a pound of fuel may be taken containing 15,000 B.Th.U. Analysis of the waste gases shows incomplete combustion represented by 500 units. Then the efficiency of combustion is

$$\frac{15{,}000-500}{15{,}000}=96\cdot\dot{6}\dot{6} \text{ per cent.}$$

The generated units, 14,500 in number, now contained in the furnace gases leave for the chimney with 2,500 units. The apparent efficiency of the boiler furnace is thus

$$E=\frac{14{,}500-2{,}500}{14{,}500}=82\cdot76 \text{ per cent.}$$

But if, of the 2,500 units in the waste gases, 1,500 units are represented by the heat below boiler-pressure temperature, it will not be possible to use these, and the real efficiency of the heating surface is

$$E_1=\frac{(14{,}500-1{,}500)-1{,}000}{(14{,}500-1{,}500)} \text{ or } 92\cdot3 \text{ per cent.,}$$

for the boiler has absorbed 92·3 per cent. of the heat offered it above its own temperature.

Thus this efficiency will be better with low-pressure boilers than with those more highly pressed, and therefore at higher temperature.

The boiler having absorbed 12,000 heat units, only 11,500 appear in the steam. Then the use efficiency will be $95\cdot8\dot{3}$ per cent. The overall efficiency will be nominally

$$\frac{11{,}500}{15{,}000}=76\cdot\dot{6}\dot{6} \text{ per cent.,}$$

but the true efficiency will be

$$\frac{11{,}500}{(15{,}000-1{,}500)}=85\cdot\dot{1}8\dot{5} \text{ per cent.}$$

of the possible. Possibly some of the very high efficiencies claimed occasionally may be stated thus in the correct manner without it being stated that the ordinary method has not been followed.

The efficiency of the general process of steam production is improved when the boiler is made to do duty only as an evaporator, an end that is attained by supplying it with water which has already been heated to the temperature corresponding with the pressure of the steam in the boiler. The feed water must be partly raised in temperature by heat which would otherwise be wasted. It is thus first heated, it may be by waste steam, and is then passed through pipes exposed to the furnace gases which have left the boiler. These gases will be considerably hotter than the boiler, because with no reasonable area of heating surface is it possible to reduce the waste gases within 100° Fahr. or more of the boiler temperature. Nor is it then possible to reduce the temperature of the waste gases as they leave the feed-water heater to so low a temperature as the initial feed. The final chimney temperature is rarely less than 300° or 400° above atmospheric temperature. At this point it becomes obvious why the use of air in the furnace should be a minimum. Assume the case of 13 lb. of gases per pound of fuel and the case of 26 lb. of gases. It is clear first that for a given production of heat the gases must move nearly twice as quickly in the latter case as in the former, and as they will have a less temperature head above the boiler-plate temperature, the transfer of heat will tend to be less efficient and the final temperature will be higher. In 13 lb. of hot gas there will be less than half the heat carried to waste which is contained in 26 lb. of gas at a higher temperature. Excess of air is thus a very direct loss. A final temperature of 350° with say 15 lb. of waste gas represents say 1,125 B.Th.U. above atmospheric temperature, or a loss of 7½ per cent. of the calorific value of the assumed 15,000 heat units in the coal. With a total of 25 lb. of waste gas at 400° Fahr. above atmospheric temperature the loss becomes 2,500 B.Th.U., or $16\cdot\dot{6}\dot{6}$ per cent. Excess of air in the furnace is thus a serious defect, and will represent a difference of efficiency of 10 per cent. to 5 per cent. as between ordinary and good practice.

Where combustion produces a high percentage of CO_2 it is usual to expect a high efficiency, but if any serious percentage of CO be present as well, it might be better to reduce this by the use of more air, destroying the CO entirely, than to continue the waste of fuel which is shown where CO is present. Thus if 15 per

cent. of CO_2 is shown with 1 per cent. of CO, the weight of carbon represented is :—

$$\begin{array}{lll} \text{In the form of } CO_2 & 15 \times \frac{12}{44} = 4{\cdot}1 & \text{of carbon} \\ \quad ,, \quad ,, \quad CO & 1 \times \frac{12}{28} = 0{\cdot}43 & ,, \\ & \overline{\quad 4{\cdot}53 \quad} & \end{array}$$

The heat value of this carbon is nearly 66,000 units, but only 61,700 units are produced, since 4,300 units are lost in the incomplete combustion of the 0·43 lb. converted only to CO. The combustion efficiency is reduced to 93·5 per cent. by the presence of 1 per cent. of CO. It is thus easy to see why an excess of air and a lower percentage of CO_2 may be more economical than high CO_2 and a small percentage of CO, and this will be the more marked as the surface of the economiser is more liberal and the chimney temperature is low. But the presence of CO may be due to lack of air mixture and the extinction of combustion by too early contact with cold boiler surfaces. Hence the necessity of conserving the temperature of a furnace until combustion is complete, and of providing a reasonable supply of air in excess of the chemical minimum in order that no carbon may go short of oxygen.

The minimum of air can only be secured by the arrangement of an impracticably long run for the gases in a non-heat absorbent furnace, for given a sufficient length of run it can only be a question of time for each atom of carbon to meet its atoms of oxygen. But practical considerations demand boilers and furnaces of reasonable length, and the impossibility of giving perfect mixture of exact chemical equivalents of air and fuel necessitates the addition of an amount of air beyond the chemical minimum. There are, however, good reasons to think that the transmission of heat from hot gases to boiler plate is more rapid when the velocity of movement of the gas is increased. If an additional amount of air be admitted to a furnace per unit of fuel burned, the velocity of the gases should be increased, and this increase of velocity will help to increase the rate of transmission of heat. Perhaps too much stress is laid on this by some writers, who should not overlook the fact that the smaller weight of air means higher temperature and therefore greater volume per unit weight, and the initial velocity of the greater weight of colder gases is not so much greater than the velocity of the smaller weight of hot gas as the relative weights would signify. But as the gases approach the same final temperature the greater weight must have a larger bulk, and the velocity ratio steadily increases with distance from the furnace, and on the whole some of the disadvantages of excessive air are diminished.

It ought hardly to be necessary to draw attention to the reduction of efficiency from the effects of scale. As between a clean plate and one covered with scale there are published tables showing the reduction of efficiency. But it must be observed that this is the reduction calculated upon a definite area of plate clean, and dirty or incrusted. But it will rarely be correct to estimate the reduction of boiler efficiency upon such a basis. A strong boiler is rarely incrusted all over; the furnace plates of Lancashire boilers in particular have a singular way of throwing off scale while quite thin, and the deposit of scale in a Lancashire boiler to any thickness usually occurs on parts against the outer flues, and if these were wholly removed the boiler would not show very great reduction of efficiency. If any part of a boiler is reduced in efficiency by scale, the gases leave that part and reach other parts at a higher temperature than otherwise they would do, and a certain compensation is thus afforded.

General efficiency of heating surface appears to be promoted by rapid movement of the heated gases upon one side of the plates, and still more by rapid movement of the water upon the other side, though it might well be supposed that a plate exposed on one side to hot gas would easily be cooled by water on the other side. Experience points, however, to the excellent effects of supplying a boiler with feed water of the boiler temperature, that is to say, the boiler is made to do duty only as an evaporator, and in no sense as a feed heater. The inventor of the Solignac boiler held that the tubes of a water-tube boiler should be fed with a limited supply of water only, in order that all heat passed into the water should at once become latent. In Miss Bryant's experiments on heating of plates, a curious effect was

noticed when on several occasions the water vessel boiled dry. The plate suffered a sudden fall of temperature, due to the very rapid evaporation which took place as the plate became nearly dry. May not this be due to the cause claimed by M. Solignac?

Colonel Crompton claims that by fully heating the feed water the output of a boiler may be doubled or trebled. So large an increase may be due to the easy working of the boiler before the change was made, but the effect of fully-heated feed water has been secured by means of the internal controlling tubes of the Cruse superheater, and excellent results have been obtained in boiler capacity or output. Boiler efficiency is promoted with the general efficiency improvement of a steam generating system by carrying out the process in stages. In producing steam the source of heat is not the theoretical hot body maintained at a fixed maximum temperature, nor is the working liquid a fluid at maximum temperature acquiring its latent heat energy at that temperature. On the contrary, the steam is made from a cold raw material, and the heat supply is a stream of hot gas which becomes cooler as it gives up its heat to produce steam. These practical considerations, therefore, make it necessary to perform both heating and cooling operations in stages, the heated body being brought to bear in succession upon the cold body so as to enable the final temperature of the now cooled hot body to be utilised upon the cold body while cold. By expenditure upon water heaters, air heaters, and by dividing these into stages also, it would be possible to secure greater efficiency than is now attained, but the saving of low temperature heat demands so extensive an area of contact of heat transfer surfaces that a point is soon reached at which commercial considerations step in to limit expenditure. Probably the best practice to-day would be where a fan draws air through a heater placed in series with the water heater and the boiler furnace; the water heater of ample size supplied from the hottest available source of water; the boiler fed with this water fully heated either by the tubes of the water control of the superheater, or by steam; and a furnace suitably shaped, with a sufficiency of refractory material to enable combustion to be effected with a small excess of air above the chemical minimum.

It will help to elucidate many obscure points if it be remembered that while the efficiency of boiler heating surface is rated on the mean evaporation per unit area of all the heating surface, yet most of the evaporation is performed by the earliest portions of the surface when exposed to the highest fire temperatures, and the capacity of evaporative effect possessed by boiler heating surface is many times the average customarily stated. It is to be feared that extended boiler surfaces would often be better employed if transferred to the next lower stage of feed-water heating surface, while this latter in its turn might with advantage be divided into two divisions in series, thus making in all five stages in the heating process: (*a*) by exhaust steam; (*b*) (*c*) by waste gas; (*d*) evaporative only by fire heat; (*e*) superheating by maximum possible temperature heat that can be safely employed.

As an illustration of the relative value of different parts of a boiler it has been said that, with a water-tube boiler of four equal banks of tubes in series, probably 70 per cent. of the whole duty is done by the first bank, 15 per cent. by the second bank, and only 10 and 5 per cent. by the final two banks. Then if the total duty represents an average of 4 lb. of steam per square foot of heating surface we have $2 \cdot 8 \times 4 = 11 \cdot 2$ lb. as the rate of the first quarter, barely 2·4 by the second, 1·6 by the third, and 0·8 by the last bank. In the Lancashire boiler probably 90 per cent. of the work is done in the inner tubes or the furnace tubes, which make up 19 square feet of surface per foot of boiler length, the surface in the external flues making perhaps 16 feet. But of the 19 feet not more than 10 feet are efficient, the remainder being ashpit or ash covered. The average duty for the whole boiler is say 6 lb. of evaporation per square foot per hour; and 90 per cent. of $6 = 5 \cdot 4$ lb. done by 10 feet out of 35 feet, or an average per foot for the 10 feet of $5 \cdot 4 \times 3 \cdot 5 = 18 \cdot 9$ lb. evaporation per square foot of tube crowns, and this may very well mean perhaps 50 lb. per square foot of the furnace end of the tubes. It has

not been explained why the duty per square foot of the simple shell boiler so far exceeds that of the water-tube boiler of the ordinary types. In ordinary practice boiler efficiencies of more than 60 per cent. are, it is to be feared, rare, but under best conditions 80 per cent. may be attained. One looks doubtfully on claims which state 85 per cent., and they should be regarded with caution, and full information should be forthcoming as to chimney temperature, gas analysis, and the calorific capacity of the fuel, and the condition also of the blow-out tap which is often responsible for a good proportion of the so-called efficiency.

Boiler End Turning and Flue Hole Cutting Machine.—These two functions are generally combined, because a single setting of the boiler end suffices. The illustration, Fig. 237, is that of a machine which includes drilling as well, and that permits the two sets of operations of drilling, &c., and turning being performed on different tables at the same time. The two tables are worm driven from four-speed cone pulleys (not shown), but the radial drill has a separate drive, being an independent machine serving either of the tables. The result is that a boiler end can be turned on one table, while a flue hole is being cut out on the other at the same time. The tables are of different diameters, being 7 ft. and 8 ft. respectively, for boiler ends of 9 ft. and 10 ft. diameter maximum respectively. The mechanism of the radial drill is similar to that of other machines with the radial boring arm, the latter having a steady pin to fit in the centre of the table. The machine is back geared, and has hand and power feed. The head has a range of movement on the arm of 2 ft. 10 in., and admits a maximum of 4 ft. 2 in. between the top of table and underside of spindle. The ordinary type of machine has a single table with its radial drill.

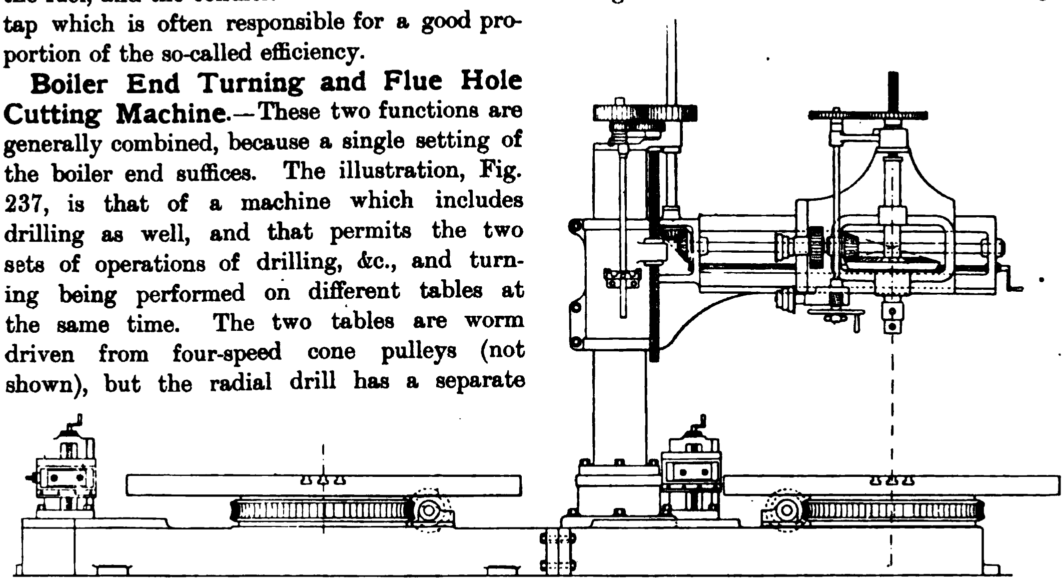

Fig. 237.—Boiler End Turning and Flue Hole Cutting Machine. (Rushworth & Co.)

Many machines of this kind have an oval hole cutting attachment. *See* **Oval Hole Cutting.**

Boiler Explosions.—These are due to one or other of the following causes. Unsuitable materials, bad design, bad workmanship, deterioration, bad working.

Unsuitable Materials.—Only a few of the largest works can afford the luxury of a testing machine, but it is easy to obtain steel of a given quality from the steel works. The average boiler steel has a tensile strength ranging between 26 and 30 tons with a 20 per cent. elongation in 10 inches. Furnace plates exposed to flame are sometimes specified to have a tensile strength of a ton or two less than shell plates, and a slightly greater ductility. A more important difference between the two classes of plates is the bending test, in which a shearing is taken about 10 in. or 11 in. long by $1\frac{1}{2}$ in. wide, heated to a low cherry red, and cooled in water of 82° Fahr. It must then stand bending to a curve, the inner radius of which is equal to one and a half times the thickness of the plate.

Though steel boiler plates are far more uniform in quality than those of iron, it is understood that every plate is tested before being worked up, tests which were not insisted

on so rigidly in the case of the more uncertain plates of iron. Every plate has a record kept of its test, and the maker's name, and a number corresponding with the test is stamped on it, and encircled with a ring of white paint to facilitate inspection. This is readily done at the steel works where the plates are trimmed. It is expensive in a boiler shop, and as the steel works guarantee and stamp all tested plates, it is usual for boiler-makers to order them to sizes required, plus the necessary allowances for planing, &c. There is no extra charge made for cutting to dimensions in the case of ordinary shapes, and usual dimensions. The extras only come in on shapes other than rectangular, though a small percentage of sketch plates is generally allowed, and in dimensions and weights exceeding those given as the maximum, though these are very large and cover all ordinary boiler work.

In many instances specimens of plates taken from exploded boilers have been tested with the result of showing a fair tensile strength, but practically no ductility, and the aspect of the fractured surfaces has been entirely granular or crystalline. This may have been the condition of the plates originally, or it may in some cases be the result of long service and deterioration. The latter results from long exposure to high temperatures, deterioration to which the best iron and steel are liable. Iron plates heated to from 400° to 600° Fahr. may lose from 25 to 50 per cent. of their ductility, while mild steel will lose about 30 per cent. This illustrates the danger of allowing plates to become overheated by the accumulation of deposit or of scale, and also of allowing contact of hot gases with flues above the water level.

Bad Design.—Bad design, in regard to the non-accessibility of parts for examination is a frequent cause of corrosion. All parts of a boiler ought to be either directly accessible, or else provision be made for cleaning out. In narrow water spaces the first is not practicable, but the latter is. Even when parts cannot be directly got at, provision can in most cases be made for ocular inspection with a light thrust through hand holes, or mud holes, or between tubes. In marine boilers often there is too little space left between the tubes; and between the nests of tubes, and the furnace crown, or the sides of the boiler shell. In the bottoms of Cornish and Lancashire boilers, between the furnace tubes and the shell, and between the flues and the sides of the shell the space is sometimes too limited. Again mud holes are made too small, or not put in the most convenient places.

Bad Workmanship.—Internal caulking has been the cause of much injury to boilers and of numerous explosions. The nicking of the plate by the careless use of the caulking tool sets up incipient grooving, and furrowing, evils which tend to increase and develop. Caulking of boiler plates should always be done with a broad tool, nearly or quite as broad as the thickness of the plates. Strictly speaking this is not caulking, but fullering, and is less likely to open the edges of the plates than the use of a thin caulking tool would be.

Deterioration.—More boiler explosions occur through corrosion than from any other cause. It is a very insidious form of danger, and in some localities is likely to run to dangerous extremes without its existence being so much as suspected. It occurs in two forms, internal, and external, the former relating to that which goes on within the boiler, the latter to that which goes on without, the first occasioned chiefly by bad feed water, or by undue local straining, the latter by setting in damp localities and by bad setting on the boiler supports. As these two types of corrosion are due to entirely different sets of causes, we will consider them separately.

External corrosion is the most prolific cause of boiler explosions. Internal, though a very frequent cause, is not nearly so injurious as the other form. The reason is that better opportunity usually exists for the inspection of the interior portions of boilers than the exterior. There are few parts of the interior of boilers that are not open to inspection, but such is not the case with external parts. In land boilers there are the various brick-work seatings, often damp, and the coverings that interfere with inspection, and which steam users are loth to remove unless convinced of the absolute necessity of doing so. Even without removal of portions of the brick-work the condition of the flues is often so bad, being choked with soot, that a proper examination of the

parts that are not covered with the brick-work is often impossible.

The reason, therefore, why external corrosion has been so prolific a cause of boiler explosions lies in the difficulty of its detection, since it usually occurs along the bearing edges of the supporting walls of the flues. Damp accumulates here, and corrodes the plates, and the corrosion being concealed from view often remains undetected until it has eaten through or nearly through the plates. Two reasons may exist for this, the setting of the boiler in a situation naturally damp, or the existence of leakage from the boiler itself. The evil is aggravated by making the top of the bearing walls on which the boiler rests too wide, and by allowing lime or mortar to come into contact with the boiler. To prevent this, a boiler should not be set in a damp situation. Or if the choice does not permit of any other, then special precautions ought to be taken to prevent the damp from coming near the boiler seatings.

There are, in all boilers, seams and fittings more or less covered over, and these are liable to straining, leakage, and corrosion. In marine boilers the bottom parts are often very difficult of access, and frequently damp. Longitudinal seams should be always kept off the brick-work, because leakage is always liable to occur from these. Many explosions have occurred due to corrosion and wasting of shell seams on damp seatings. Boilers have been inspected, insured, and passed, and the hidden danger not been suspected.

Taking internal corrosion next, this is designated by different terms according to its character. It may be general or local. In the first case, large areas of plates will be reduced in thickness, the wasting occurring with tolerable regularity. In the second case, the plates will be pitted or covered with minute depressions similar to the markings of small pox, or continuous narrow lines of corrosion, termed grooving, will occur in the vicinity of seams of angle iron, in the roots of angle irons, and other relatively rigid parts. Corrosion may be simply due to the presence of acids in the feed water, as in the case of general wasting, or it may be due to local stresses set up by the expansion and contraction of the boiler in working, intensified or not by the corrosive action of acidulated feed water.

When a plate is wasting uniformly, the evil may proceed for a long time unsuspected. If a plate is supposed to be deteriorating, the only certain way of testing its thickness is by drilling a few holes in it, to be afterwards filled up with screwed plugs if the plate is found all right. Sounding with a hammer will tell nothing, unless the plate is very thin.

In the case of a violent boiler explosion which occurred at Stannington near Sheffield in 1885, causing the death of three men, the internal corrosion was so severe that the whole of the plates below the water line were seriously reduced in thickness. At the front side near the bottom where the rupture commenced the plates were no thicker than a piece of paper. The longitudinal seams of rivets over the fire appeared to be almost melted away, and the inner overlap of the seam for a length of about 10 feet was wasted between the rivet holes as thin as a knife edge. There was no scale on the plates, but severe corrosion due to the bad feed water used.

Whatever lessens the homogeneity of plates tends to induce and accelerate corrosion. To say nothing of the obvious laminations and blisters in iron plates, there are the minute spaces in steel plates due to the air cavities present in the ingots. There are also portions more or less dense caused by work done on the material in rolling, bending, flanging, and hammering.

Simple grooving due to straining actions alone is very difficult of detection. But if the grooving is aggravated by the corrosive action of acids it can be readily discovered. The grooving due to straining may be like a fine longitudinal crack or fracture, only perceptible to a most careful search, assisted perhaps by drilling. But when the crack is acted upon by acids it becomes widened, and wasted into a relatively broad furrow, hence the term furrowing.

The grooving at the front end plate of a Lancashire or Cornish boiler is almost always more severe than that at the back end. The reason is that the arching or hogging of the furnace tube is always greater near the front

over the furnaces than near the back. This occurs chiefly at the time of lighting up and for an hour or so afterwards, or until all the boiler parts have reached about the same temperature. That the amount of hogging is greater at the front end than the back was proved by Mr Lavington Fletcher in experiments with gauge rods. The rods were attached to the furnace crown at intervals, and passed up through stuffing boxes in the shell. The curve assumed by the furnace was not regular, for the gauge rod at a quarter of the length of the boiler from the front end showed as much rise, and in one case $\frac{1}{16}$th more rise than a rod placed midway in the length. The furnace tubes rose $\frac{3}{8}$ in. when the flames passed round the brickwork flues in the ordinary way, and $\frac{1}{2}$ in. when they were led directly into the chimney without heating the outer shell.

The bottoms of Lancashire boilers are subject to strain due to the fact that the temperature is lower there than elsewhere, and the expansion of the plates there is consequently less than that of the flue tubes. When cold feed water is delivered at the bottom of the boiler, the evil is intensified, and rips of the transverse seams have frequently occurred by reason of this straining.

Many cases have come under the notice of boiler inspectors of the blow-off cocks, and the front end plates of horizontal boilers having been so encased in brick-work that their condition could not be seen, and so corrosion has gone on for a long while without being detected, while the same parts have also been subjected to severe strains through being bound fast, instead of being left free to move with the expansion of the boiler.

Grooving and furrowing are liable to occur in longitudinal lap-jointed seams, being due to the tendency of the internal pressure to impart a truly cylindrical form to the shell. The tendency is then to assume a kink at the seam. On release of the pressure the seam returns to its original position, and this constant working starts a crack or fissure, which is liable to increase in dimensions, and to be enlarged by incessant straining, and the corrosion of acids. For this reason it is desirable to use butt joints, double strapped, this being the only way in which a truly circular form can be maintained. In small boilers subject to moderate pressure only, lap seams are frequently used, but such a form of joint is quite inadmissible in any boiler, large, or small, subject to high pressures.

Grooving is apt to occur also at the edges of the circumferential ring seams of horizontal boilers, caused by the working, due to the difference of expansion which takes place. It also happens around the roots of the angles, or of flanges by which the shells are riveted to the end plates. In Cornish and Lancashire boilers it often happens around the attachment of the flues to the end plates, due also to the cambering caused by the difference of temperature between the top and bottom of the flue. In vertical boilers it is found around the angle iron rings, or the flanges which unite the uptake to the shells, and close to the foundation ring.

Grooving occurs more seriously in boilers of small than in those of large diameter. Thus, while the shells of Lancashire boilers are relatively free from this, it is apt to occur in the barrels of locomotive boilers, and the records of explosions show a large proportion attributable to this cause. And it must be remembered that such failures would be much more numerous but for the frequent and severe examinations to which such boilers are subject.

There are two types of grooving, the difference in which was pointed out by Mr Fletcher, one broad, the other narrow,—a mere nick, the first being apparently due to single riveting, the second to double riveting. In one case mentioned by Mr Fletcher the grooving occurred in the steam space, and not in the water space as generally happens. Such narrow nick grooves are difficult of detection.

Furrowing is partly chemical, partly mechanical. It does not occur with all waters, and it seldom happens above the water line. Furrowing may be commenced by mechanical action, as when a plate bends or springs at a seam. Or it may begin at a joint where the caulking tool has been driven into the metal, cutting below the scale or skin. In either case clean metal becomes exposed to the action of acidulated water which corrodes it. The evil is intensified

by the mechanical action of repeated bendings, until a deep and narrow furrow results. In order to diminish the risk, all seams should, as far as practicable, be placed above the water line. Lap seams should be avoided below the water line, butt joints with covering straps being used.

Probably the most injurious form of boiler deposit and scale is that which has only been known since the introduction of high pressure steam. It is derived primarily from the lubricating oils of animal and vegetable origin which are used in the cylinders, by reason of the dryness and non-lubricating character of the superheated steam. These also pass over into the boiler, being carried with the exhaust steam into the feed water. They float on the water as scum, until becoming entangled with solid particles of carbonate and sulphate of lime, the scum becomes of the same specific gravity as the water, and is then carried about with the circulating currents until it fastens on the surfaces of the plates. The portions which become deposited on the crowns of the flues cause overheating.

That familiar type of corrosion known as pitting is due to galvanic action, and is the result in the first instance of minute specks of foreign matters, as carbon, or manganese originally present in the iron or steel, and which being electro-negative to the metal induces local corrosion. Then the oxide of iron formed is electro-negative to the metallic, and induces further corrosion, with an increase in the size of the pit both in diameter and depth. Pitting once started must almost inevitably increase, because each portion of oxide as it forms increases the quantity of electro-negative substance which acts upon the iron.

Over-straining leads to many explosions. This is due to the effects of heat acting in different degrees upon different parts of a boiler. The parts in contact with the fire expand most. The expansions of metal produce strains of many tons per square inch, and a boiler therefore, which is designed so badly that these become excessive, will in some cases fail directly. In most instances, however, the period of rupture is long delayed, and does not happen until certain vital sections have become deeply grooved or furrowed by reason of the incessant working action produced by the movements due to heat.

Boiler Feed.—The supply of water introduced to a boiler. It is introduced cold, or hot, is pumped, or injected automatically. The old practice was to bring in cold feed near the bottoms of horizontal boilers where the circulation is sluggish, with the risk of the cold water causing contraction of plates and leakage of rivets. The proper way, now universal, is to introduce it about midway between the flue crown and the working level of the water. It is also carried along some way and distributed through a perforated pipe. The feed is brought in through the front plates of Cornish and Lancashire types, in verticals at any convenient position round the boiler, but at a horizontal location about midway between the fire box crown and the normal water level.

See also **Boiler Efficiency, Boiler Feed Pump, Feed Waters, Injector.**

Boiler Feed Water.—*See* **Feed Waters.**

Boiler Feed Pump.—This class of pump includes several types. The commonest and simplest is one that is driven by an eccentric from the crank shaft, and is of short stroke. An old type, less used now, is driven from the crosshead, and has therefore the same stroke as the engine piston, and is not suitable for high-speed engines. Pumps of these types are not adapted for large engines, the boilers of which are preferably fed by steam pumps, either of simple or of compound types, and independently of the working of the engine. Any pump must be of large capacity. It ought to be able to supply double the quantity of water evaporated by the boiler in order to have a margin of security against leakage and irregular working, blowing off, blowing the whistle, or using auxiliary engines. For a condensing engine, the supply is taken from the hot well, and in the usual surface condenser is fresh water.

Two examples of feed pumps are given in Figs. 238, 239, both by Messrs J. P. Hall & Sons, Ltd., of Peterborough.

Fig. 238 is a direct-acting single cylinder double-acting pump of 18-inch stroke, and having an engine cylinder of 6-inch bore. It makes 13 strokes per minute, and is equal to

a duty of 2,725 gallons per hour. The steam valves are of circular form, and an impulse valve, also circular, regulates the admission to the steam valve, its motion being derived through the levers and rods from the motion

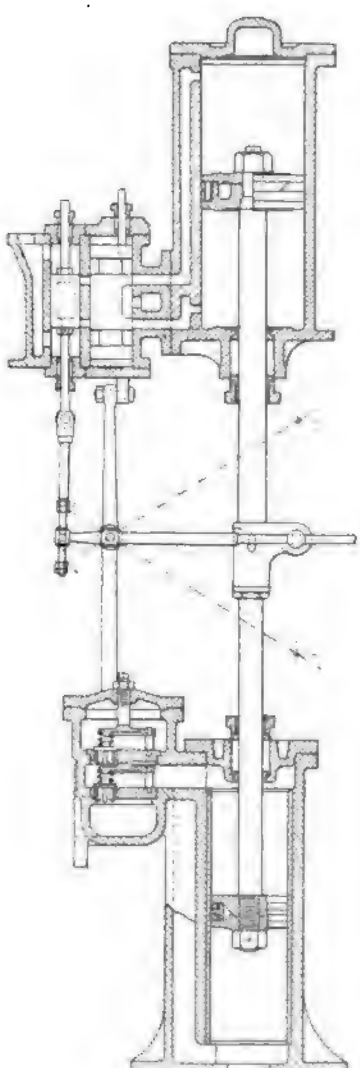

Fig. 238.—Feed Pump.

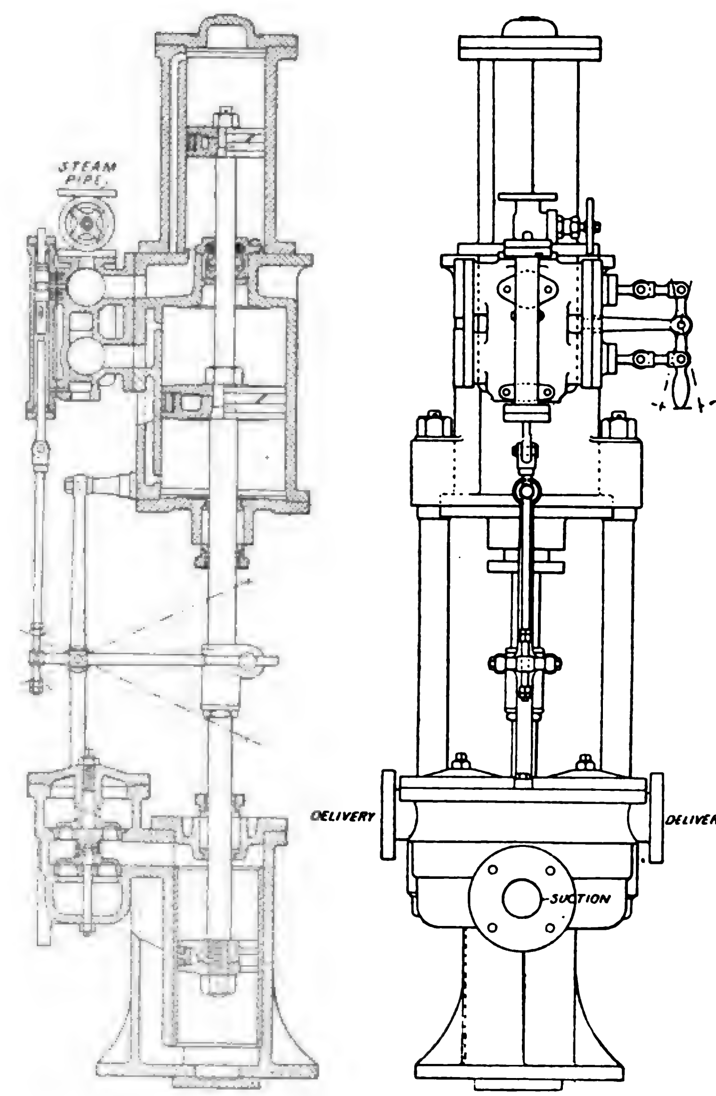

Fig. 239.—Compound Feed Pump.

of the piston rod. The pump (below) is lined with gun metal, and its piston has ebonite rings. The rod is of rolled manganese bronze, and the valves and seats are of gun metal.

The compound direct-acting feed pump is shown in Fig. 239; the principal feature in this is that the compounding permits of a high-pressure cylinder,—the uppermost one in the figure—being no larger than the pump cylinder—the lowermost—with a great saving of steam, approximately 50 per cent. by comparison with the ordinary single cylinder type of pump. The expanded steam comes into the low-pressure cylinder, mounted in tandem with the high press. In this example the HP. cylinder is $6\frac{1}{4}$ in. diameter, and the LP. $9\frac{1}{2}$ in., the pump $6\frac{1}{4}$ in., and the stroke is

12 inches. The number of strokes per minute is 14, and the duty is 2,200 gallons per hour. The valves are of circular section. The upper valve is the high-pressure one, and the lower or low-pressure valve is operated from this by a lever seen in the external elevation. The valves are controlled by the auxiliary valve on the front of the steam valve casing, and this is operated from the motion of the piston rod of the engine by the rocking lever and connecting rods seen. The lever which connects the two valves has a handle, the purpose of which is to start the pump, effected by placing the high-pressure valve in the opposite position to that it would occupy if the pump were working. This has the effect of filling the high-pressure cylinder with steam, so that when the positions of the valves are reversed, the steam is exhausted into the low pressure, and the action is continuous. Cushioning is effected in the low-pressure cylinder by casting the main ports at some distance from the end, so bringing the piston slowly to rest, and allow the pump valves to reseat themselves before the commencement of the next stroke. The small amount of steam compressed escapes through a very small port at the end.

Generally feed pumps are fitted in duplicate, so that one set can be overhauled and repaired while the other is working. The feed pumps require frequent attention, since if they should cease to work, or work inefficiently, damage may ensue to the boiler in a short time. The valves must be examined periodically. Trouble often arises due to the presence of hot water, though the advantages of using water as hot as possible are obvious. Hot water has more elasticity than cold, and is therefore able to suffer compression before it can overcome the boiler pressure.

Boiler Fittings.—These are the manhole doors, mudhole ditto, furnace bars, bearers, doors, dampers, and any other parts which are usually considered distinct from mountings.

Boiler Flue Flange Drilling Machine.—A special machine for drilling the rivet holes in the flanges of the furnace flues of horizontal boilers. A couple of flue lengths are placed in position, with the axis vertically, on a chuck, and clamped, or held with tacking bolts. The chuck is rotated by worm gear and hand wheel, and pitching is effected by change wheels. There are two standards for the drilling heads in a complete machine. They are bolted to extensions of a bed, the centre of which carries the chuck. The drilling heads have vertical adjustments on the standards, and radial adjustments on the saddle, with a good range. Some of these machines also have a horizontal drilling spindle for drilling the rivet holes in the sides of the flues for cross tubes.

Fig. 240, Plate XVI., shows a double-drilling machine for flue flanges, having a special form of drive to the drill spindles, so that they may work while the flanges are placed together, as shown, with the caulking ring *in situ*. The capacities of the machine are as follows:—Maximum drill centres 5 ft., minimum ditto 2 ft. 1 in., horizontal range of each drilling head 1 ft. 5½ in., maximum height admitted, from top of chuck to drill point, 5 ft. 1 in., minimum ditto 1 ft. 3 in., the chuck grips from 2 ft. 11 in. to 4 ft. 7 in. diameter.

In another form the flue, carried on a horizontal chuck as before, is flanked with standards which carry a cross rail along which the drilling heads have horizontal adjustment, the cross rail being vertically adjustable. Some of these are much elaborated to combine provision for turning as well as drilling, and for tapping, and tube-hole cutting. They resemble a planing machine in having cross slide, tool boxes, and bed, along which the saddle of the chuck slides, provision for running the chuck for turning, for pitching by change wheels and worm gear, and in having counterbalanced heads fitted for drilling and tapping, with variable feeds, and a separate tool box for turning, with another tool box on one of the housings. An example is shown in Fig. 241, Plate XVI., taking flues from 1 ft. 10 in. to 4 ft. 6 in. diameter, and 1 ft. 10 in. to 4 ft. 6 in. height. The pitching is effected by the hand wheel seen to the left, which through the medium of change wheels rotates the chuck through a portion of a circle at each complete turn of the hand wheel.

Boiler Flue Flange Turning Machine.—A type used for turning the flanges of the furnace flues of horizontal boilers in readiness for drilling and riveting them up in lengths,

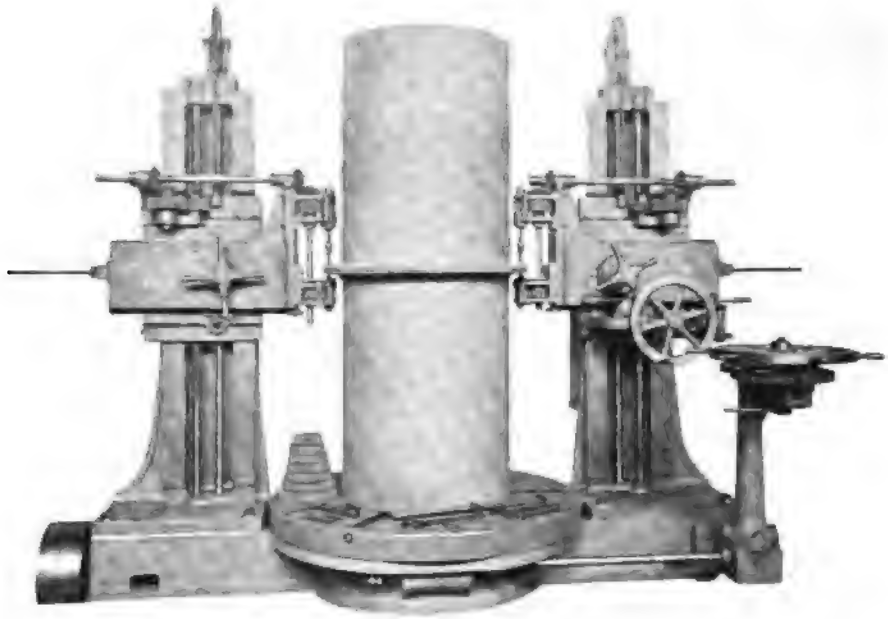

Fig. 240.—Boiler Flue Flange Drilling Machine. (Rushworth & Co.)

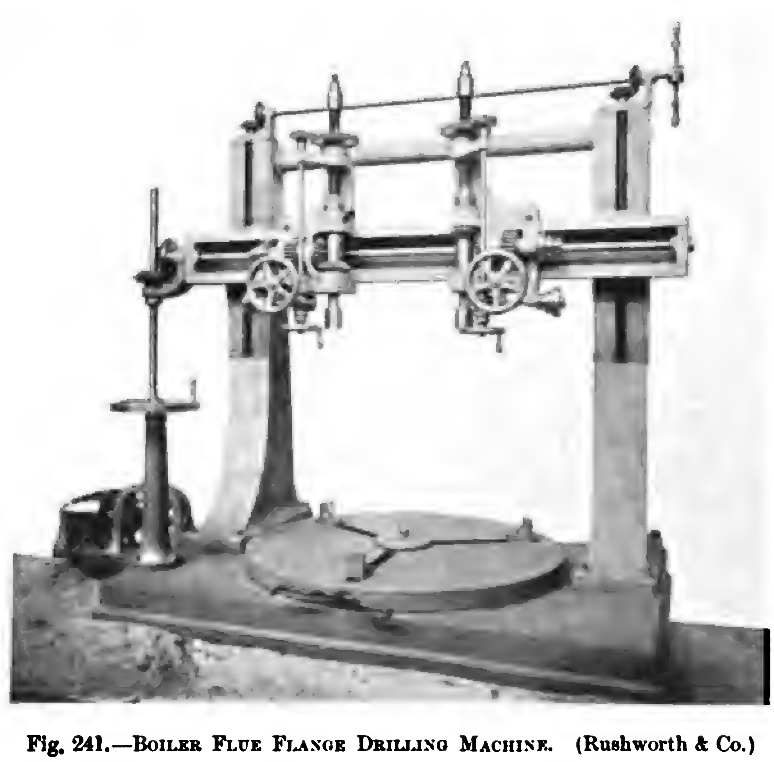

Fig. 241.—Boiler Flue Flange Drilling Machine. (Rushworth & Co.)

To face page 236.

and for attachment to end plates. The flue length is chucked with its axis vertically, the chuck, Fig. 242, being of the jaw type, having simultaneous movements. The work table is rotated by gearing, and the tool is held in a box having radial and vertical adjustments. The speed of rotation may be uniform, or a speed cone may be fitted.

Boiler Flue Flanging Machine. — This machine arose out of the necessity of substituting flanged ends for furnace flues in place of the old angle iron joints. The flue lengths being first bent and welded have their flanges produced by a rolling process, which though gradual is rapid, and is easily done at one heat. In a few machines of this class the flue is held with its axis vertically on a chuck, but in the majority it is held at an angle. The operation is as follows: The flue is pinched in a chuck, Fig. 243, rotated by power through bevel gears, and while supported thus at the bottom end, and resting by its periphery on friction rollers near the other, its upper end is subject to a turning-over process by a roller carried in a sliding head, the resistance to which is supplied by another roller behind the flange.

In the earlier machines the bracket which carries the flanging rollers is pivoted on a pin, and is actuated by a quadrant worm rack, the idea being to facilitate the gradual turning over of the flange, the curvature being regulated by a hand wheel operating the worm. In the present design this is being abolished in favour of the more rigid device of a bracket having a linear movement only on its slide, with a roller bearing only pivoting, and movable bodily by mitre gears in its bracket perpendicularly to the linear movement just mentioned. This is the design illustrated in Fig. 243, a machine by Henry Berry & Co., Ltd.

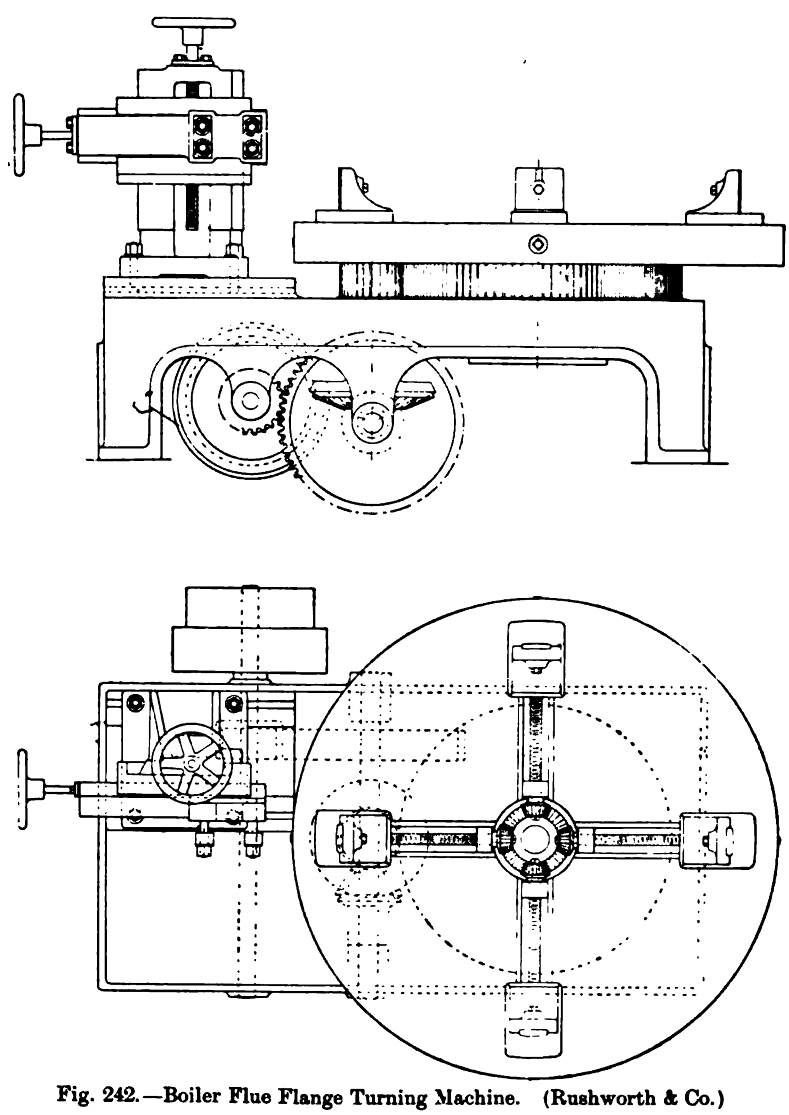

Fig. 242.—Boiler Flue Flange Turning Machine. (Rushworth & Co.)

In the group of views, A is the chuck, carrying the length of flue B. C, C are the supporting rollers adjustable along their slide by right and

left hand screws to suit flues of different diameters. D is the bearing roller under the flange, and E the turning roller, pivoted as already stated, and having its position capable of adjustment by the hand wheel F and mitre gears and screw.

commercial institutions, and in competition with each other they have done excellent work by inspection, reports, experiment, and advice in rendering boiler design, construction, and working a very exact department of engineering.

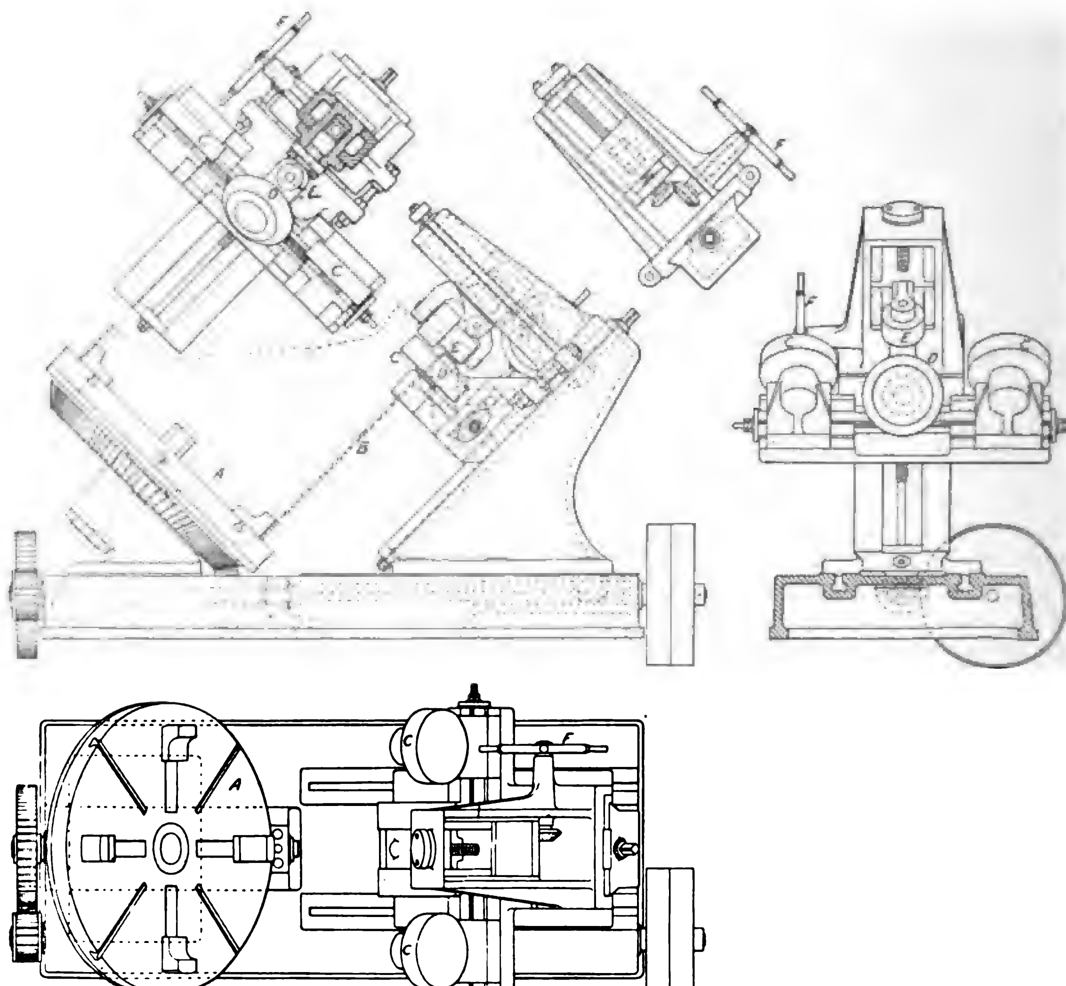

Fig. 243.—Boiler Flue Flanging Machine. (Henry Berry & Co., Ltd.)

Boiler Flues.—*See* **Furnace Flues.**

Boiler Inspection.—It was to the suggestion of the late Sir William Fairbairn that the Manchester Steam Users' Association, the pioneer of all boiler insurance companies, owed its origin in 1855. At present there are several of these companies in Britain. Though purely

In the days when steam users were responsible to no tribunal, scandalous work was done that must seem almost incredible to the younger race of to-day. Many a boiler inspector only in middle life could tell of practice that would seem to have been adopted almost with a deliberate view to court disaster. The ignorance

of steam users was in many cases simply amazing. Hundreds of lives have been sacrificed that would have been preserved under the present system of inspection. Hundreds of wretched follies in practice would never have been perpetrated if an average knowledge of the principles of boiler construction had been brought to bear upon it.

When too we compare the pressures of from 10 to 20 lb. in land and marine boilers of sixty years ago with the pressures ranging from 100 to 200 of to-day we begin to realise the magnitude of the accompanying changes in the constructive details of boilers. The developments of the modern steam engine, though spoken of as marvellous, are no more so than those of steam boilers. Imagine the total pressure on the shell or ends or furnace tubes of a high-class modern boiler, and then try to conceive the enormous strength requisite to withstand those pressures. As the strength of a chain is measured by that of its weakest link, so the strength of the minutest detail of a boiler must be estimated by the maximum pressure the boiler has to carry. Plates, seams, rivets, stays, flanges, bursting and collapsing strengths should each be strong enough for that pressure. Then besides the structural proportions of boilers, the changes of their life history must be understood. Some boilers grow prematurely old, others last longer than the average term of human life. It is largely a question of original construction, but it is also one of the wear and tear of service. Boilers are subject to many accidents and diseases, due to bad management, bad feed water, deposit and incrustation, corrosion and grooving, overheating and local stress. The diagnosis of these evils gives work to the boiler inspector, and the warding off or cure of these troubles demands continual watchfulness.

The employment of high pressures has led to greater care being exercised over the fittings and mountings of boilers, and steam users are practically compelled to take all reasonable care to prevent the risk of explosion. Faulty and unsafe fittings and mountings have therefore mostly given place to those of better construction. The lessons of many hundreds of explosions have been utilised in the direction of safer practice, and out of evil there has been evolved much good. A modern boiler manufactured according to the most approved methods of design, tested and inspected during manufacture and periodically inspected afterwards, is almost perfectly safe.

The story of boiler inspection during the last fifty years runs side by side with that of the development in boiler practice due to the introduction of mild steel in place of wrought iron, to the employment of very much higher pressures, and the developments of new types, and modifications in types. It has also been extended to include economisers, superheaters, steam-pipes, water-tube boilers, and mill engines, and also the designing of new boilers. With regard to the work of the Manchester Steam Users' Association just now referred to, and the parent of all others in existence, this Association was mainly responsible for the passing of the Boiler Explosion Acts, and for the conduct of a number of classical experiments, some of which were very costly. The Association takes a very lofty view of its own responsibilities. They have a guarantee fund, but with an income of about £17,000 a year they distribute no dividends, nor do they seek any, all surplus being utilised for advancing the knowledge of boilers and related subjects. Associations similar to the Manchester have been formed now in most civilised countries, and there is an international union, comprising fifty boiler inspection associations, who have 149,000 boilers under their inspection. The Manchester Association accept no boiler for insurance which is not first of all thoroughly inspected and found safe, or which is so constructed that it cannot in future be efficiently inspected. None is accepted if constructed entirely or partly of cast iron or similar unreliable material, among which are included some so-called cast steels and steel alloys.

The duties of boiler inspectors involve much more than can be stated in this article. They include a knowledge of the strength and behaviour of wrought iron, mild steel, and copper, the strength of riveted joints, the appearances and causes of deterioration of the various kinds noted in the article **Boiler Explosions**, the making of tests, to ascertain **Boiler Efficiency**, and they make external and internal

examinations, in brick-work flues, shells, and furnace flues; scaling, drilling, and close ocular examinations under very trying conditions of temperature. Practically the work of the boiler inspector will be found covered in the various articles in these volumes under which steam boilers and the matters relating thereto are described.

Boilermaker.—In its most comprehensive sense, as understood a few years ago, it meant a man who was capable of carrying through the construction of a boiler from beginning to completion; that is, he would be able to line off plates, punch, drill, rivet, caulk, do the angle iron work or hand flanging at the forge, put the boiler together, and execute all kinds of repairs that might be required on boilers. Boilermakers were also expected to be able to turn their hand to a job of ordinary plating. Gradually subdivision of tasks has been having the same results here as in many other trades. First of all there was the separation of the templet-maker from the actual work of the shops; flanging done by machines has to a great extent displaced the work of the angle iron smith, in the attachments of furnaces to end plates and crowns, and of barrels to end plates. Drilling to templet has taken the place of punching, reamering, and drifting, or the plates of a boiler are drilled through one another; so here another great branch of the boilermaker's work has been relegated to the driller. The men who operate hydraulic and pneumatic riveting machines have taken away another important section of the old work. The result is that except in the smaller shops, and for repairs, the occupation of the all-round boilermaker is nearly gone, replaced by the work of sectional departments.

Boilermaker's Dolly.—A flat-ended bar held up under the heads of rivets, similarly to the holding-up hammer, and for the same purpose, to offer a dead resistance to the riveting hammer.

Boiler Mountings.—These include safety valves, stop valves, back pressure valve, steam and water gauges, try cocks, blow-off cock, and fusible plugs.

Boiler Patching.—When a minute crack is discovered in the plate of a boiler, it is not always necessary to cut out the cracked portion and put on a patch. When the crack is only in an incipient stage the practice of studding is frequently adopted. That is, a hole is drilled and tapped at each end of the crack, and a screwed stud inserted. This localises the fracture, and so prevents its extension.

When putting patches on old boilers it often occurs that by the careless removal of rivets the plates become cracked, or otherwise damaged between the rivet holes. Or the seams may show grooving, or corrosion. In such cases the old rivet holes should not be utilised again, but the entire seam should be cut away, and new rivet holes made for the attachment of the patch piece.

When fitting a patch to a boiler care must be taken to make it of the correct shape, curvature, or otherwise necessary to ensure a perfect fit. If this is neglected, especially in thick plates, the riveting up strains the parts, and more caulking is necessary than when they are properly fitted before riveting. Small patches should never be put into boiler furnaces as they tend to cause overheating.

Boilers patched with pieces of plate bolted on, and cocks and mountings bolted direct to the boiler shell are seldom seen now. But such things were common in the experience of the older boiler inspectors. The practice was very bad, and has been the occasion of wasting and failure of plates. The bolts permit of leakage, which corrodes the portions of the plate adjacent thereto. Always patches should be riveted on, and mountings be bolted to seatings riveted to the boiler.

Sometimes in the case of an iron boiler which has exploded, it has been found that patches which have been put on had been laid with the grain running longitudinally, or with the axis of the boiler instead of circumferentially, which would be the direction of greatest strength.

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